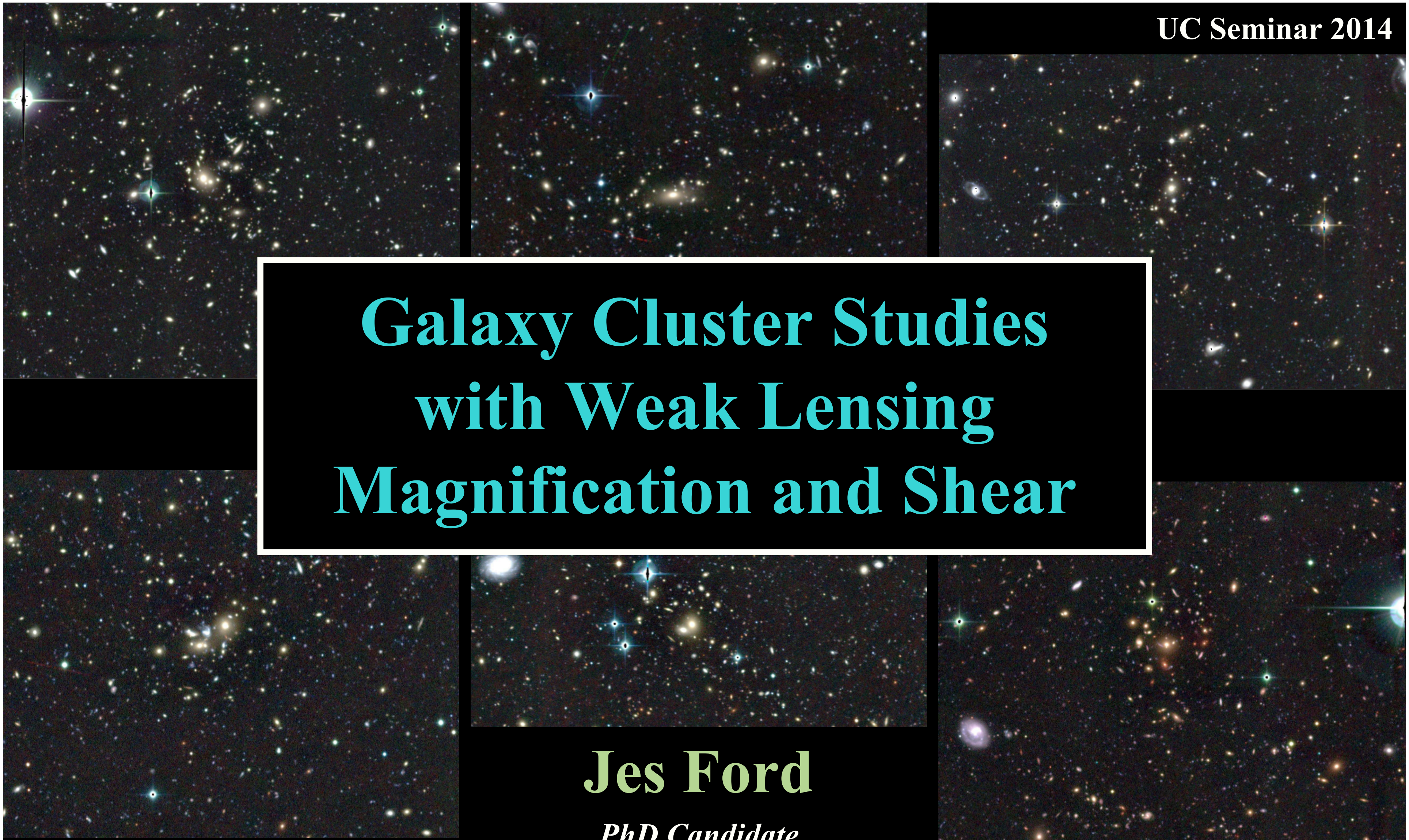


UC Seminar 2014

Galaxy Cluster Studies with Weak Lensing Magnification and Shear

Jes Ford

PhD Candidate
University of British Columbia

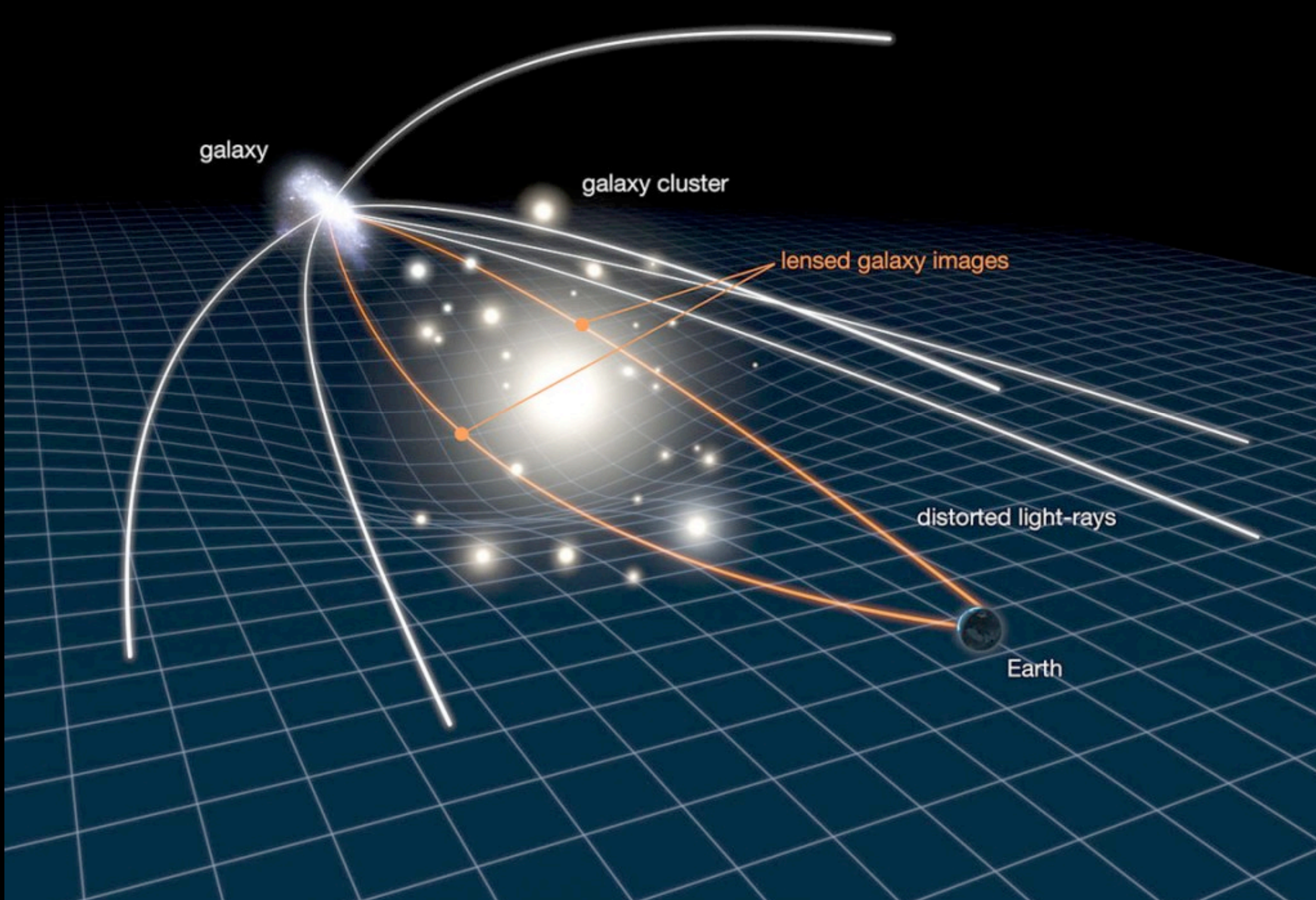
Collaborators: **Ludovic Van Waerbeke, Hendrik Hildebrandt, Martha Milkeraitis, Clotilde Laigle, Christopher Morrison, & CFHTLenS**

Outline

- **Introduction to Weak Lensing Shear & Magnification**
  - **Magnification in COSMOS**
- **CFHTLenS Galaxy Cluster Catalogs (public)**
- **Cluster Magnification in CFHTLenS**
  - **Measurement & Modeling**
  - **Cluster Mass-Richness Scaling**
- **Cluster Shear in CFHTLenS**
  - **How does magnification compare with shear?**
- **Conclusions**

Introduction:
Shear & Magnification

Gravitational Lensing



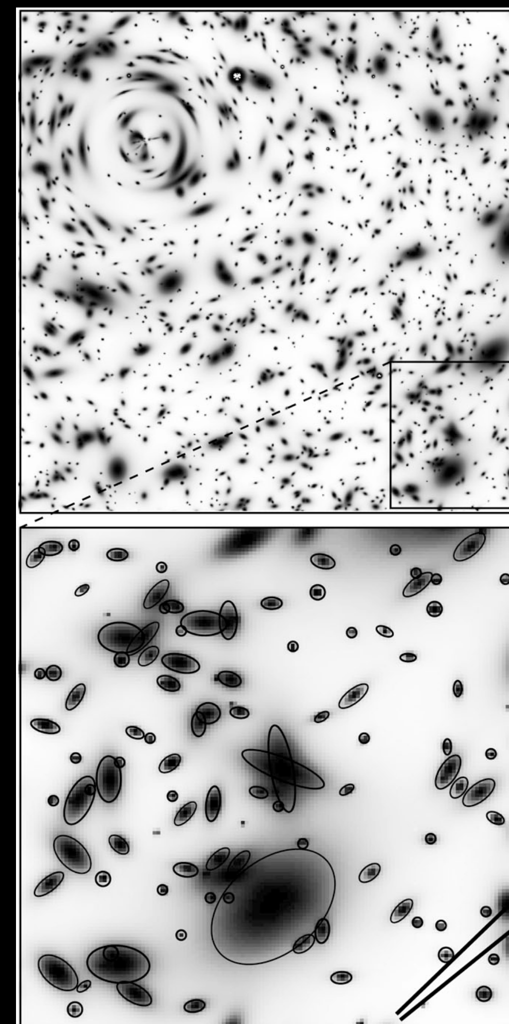
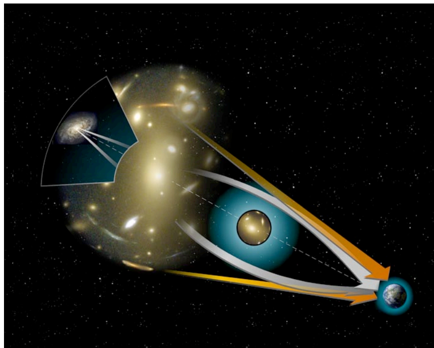


Image: NASA/ESA

Image: Mellier (1999)

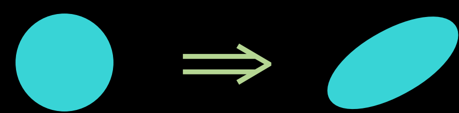


Weak Lensing

The 2 components of the Weak Lensing signal:

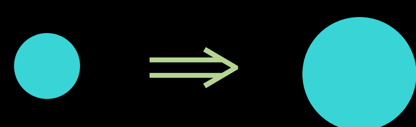
Shear (γ): *anisotropic* focusing of light rays

→ shapes get distorted

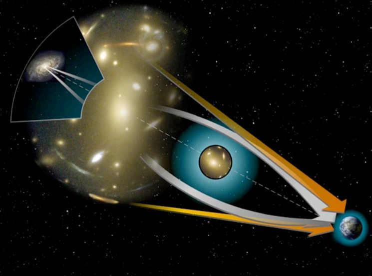


Convergence (κ): *isotropic* focusing of light rays

→ size & brightness change

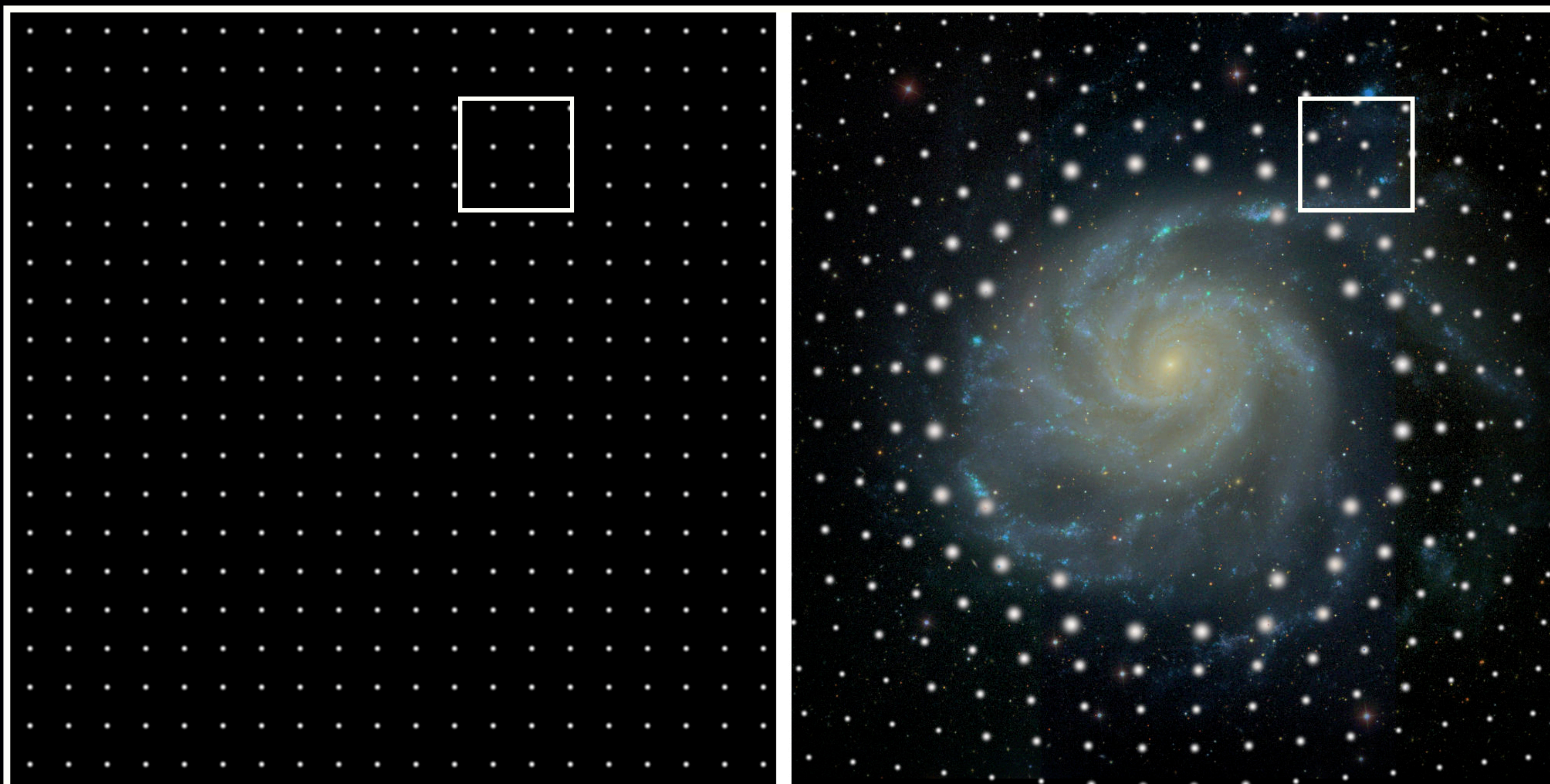


MAGNIFICATION



Dilution & Amplification

sky is stretched *sources get brighter*



Lensing conserves surface brightness

Image: SDSS

Magnification with Number Counts

Number counts are altered:

$$n(m,\theta)dm = \mu^{\alpha(m)-1} n_o(m,\theta)dm$$

- n → observed source #
- n_o → intrinsic source #
- θ → angle on sky between source and lens center

$$\alpha(m) \equiv 2.5 \frac{d}{dm} \log n_o(m)$$

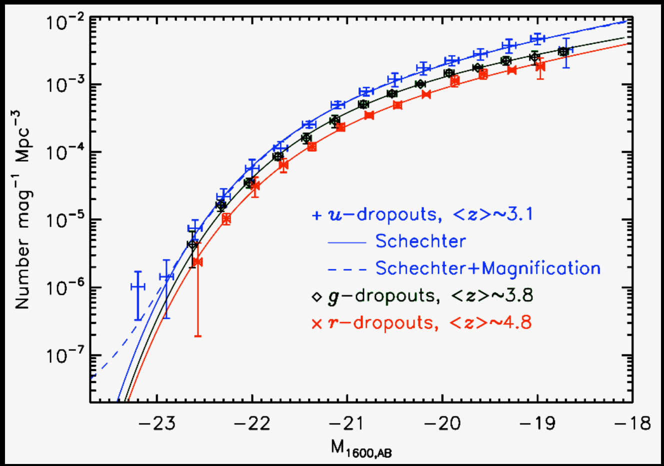
μ
depends on lens mass

α-1
depends on source # counts

$$\mu = \frac{1}{(1-\kappa)^2 - |\gamma|^2}$$

Magnification μ:

gives lensing mass, assuming some model (e.g. NFW)



van der Burg et al. 2010

Magnified Luminosity Function

We expect to observe more bright sources, and less faint sources, than we would in the absence of lensing.

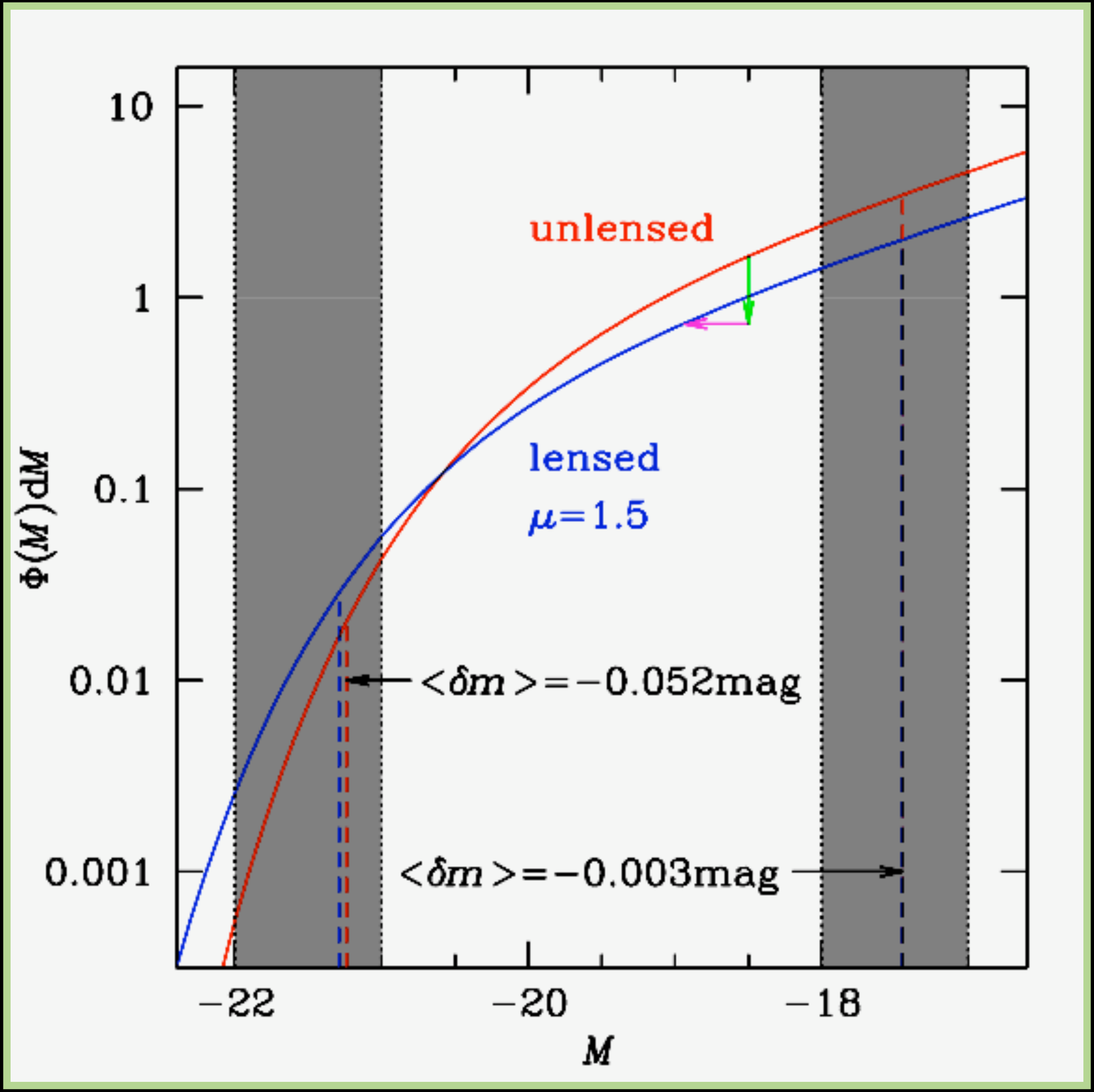


Figure: Hendrik Hildebrandt

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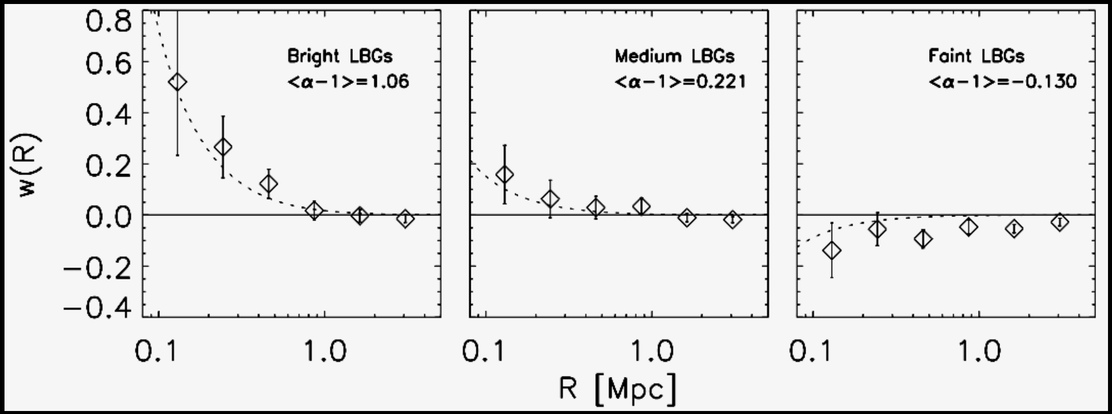
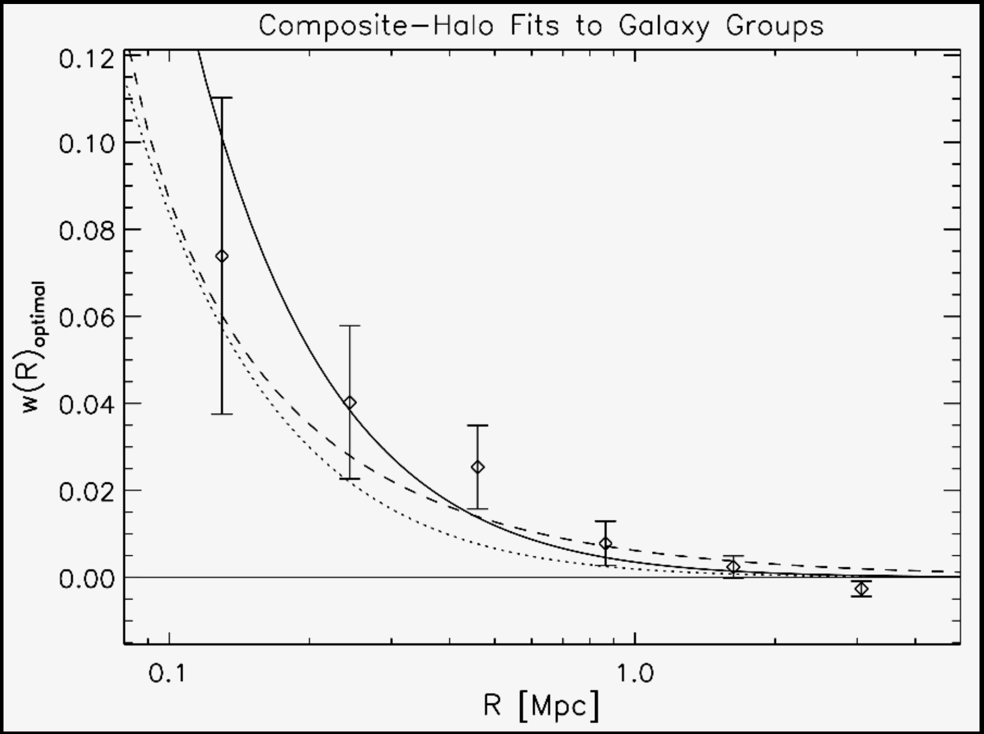
Magnification by Clusters



- 5σ in COSMOS
- 44 X-ray-selected group lenses at $0.3 < z < 1$
- 4500 Lyman-break galaxy sources at $3 < z < 5$

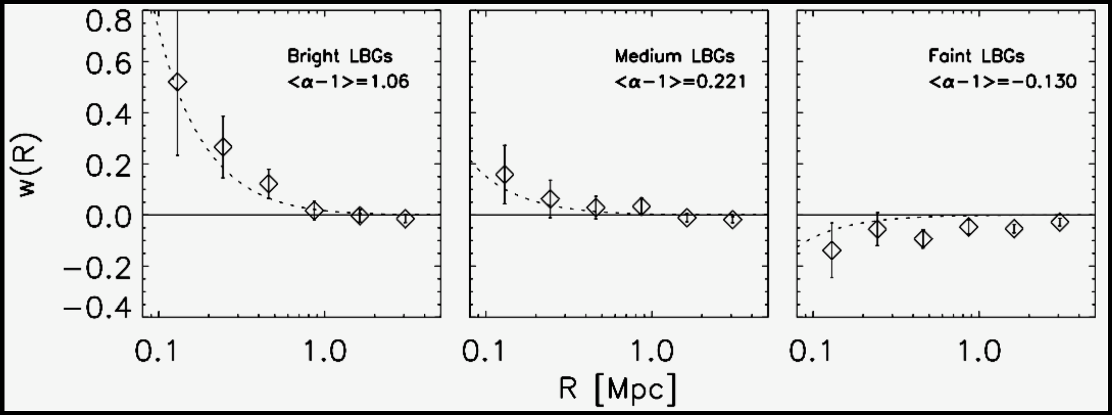
Optimally-Weighted Cross-Correlation Function:

weight each source by its (α-1), to use the expectation from the source luminosity function (Menard et al. 2003)



Ford et al. 2012

Magnification by Clusters



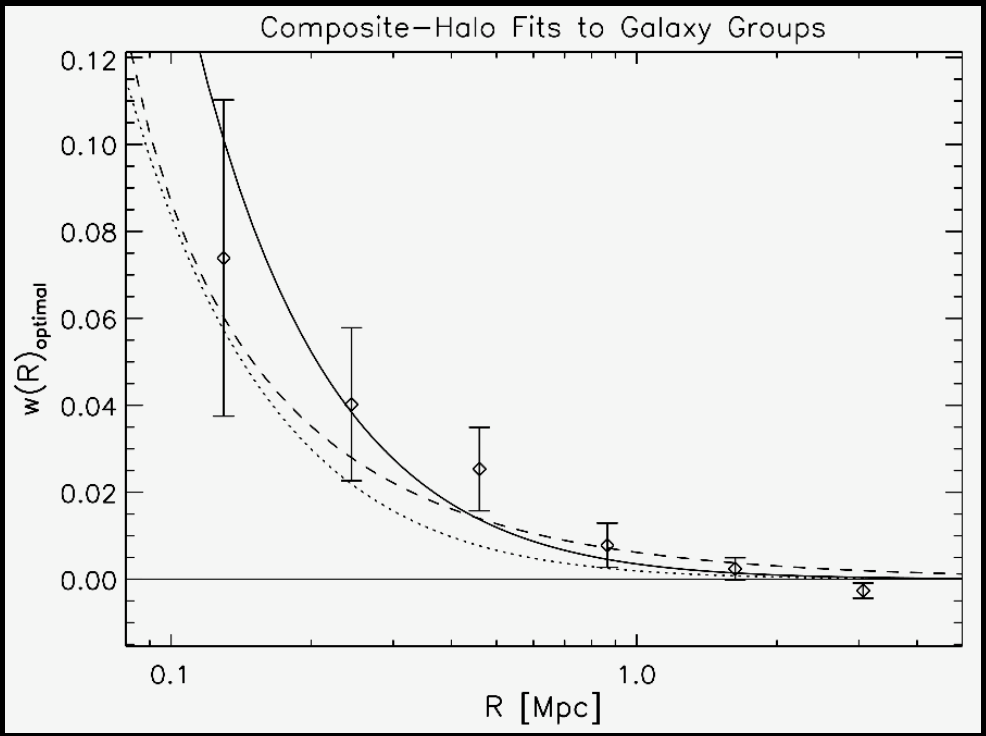
- 5σ in COSMOS
- 44 X-ray-selected group lenses at $0.3 < z < 1$
- 4500 Lyman-break galaxy sources at $3 < z < 5$

- Composite - Halo Model: Fit a scaling relation to shear masses

$$M_{mag} = a\ M_{shear}$$

- Agreement with shear masses ✓

MAGNIFICATION: 4.8σ
vs. SHEAR: 11σ



Ford et al. 2012

Shear vs Magnification

- For fixed sources, shear has higher S/N
- But measuring shapes is hard (especially high z & from ground)
- Magnification only requires source detection, so background source density can be much higher
- Shear & Magnification have completely different systematic biases
- Magnification breaks the mass-sheet-degeneracy

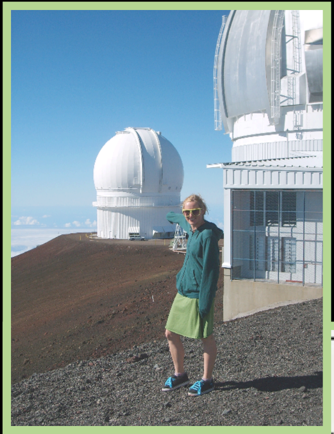
$$\gamma = \frac{\Delta\Sigma}{\Sigma_{crit}} \qquad \kappa = \frac{\Sigma}{\Sigma_{crit}}$$

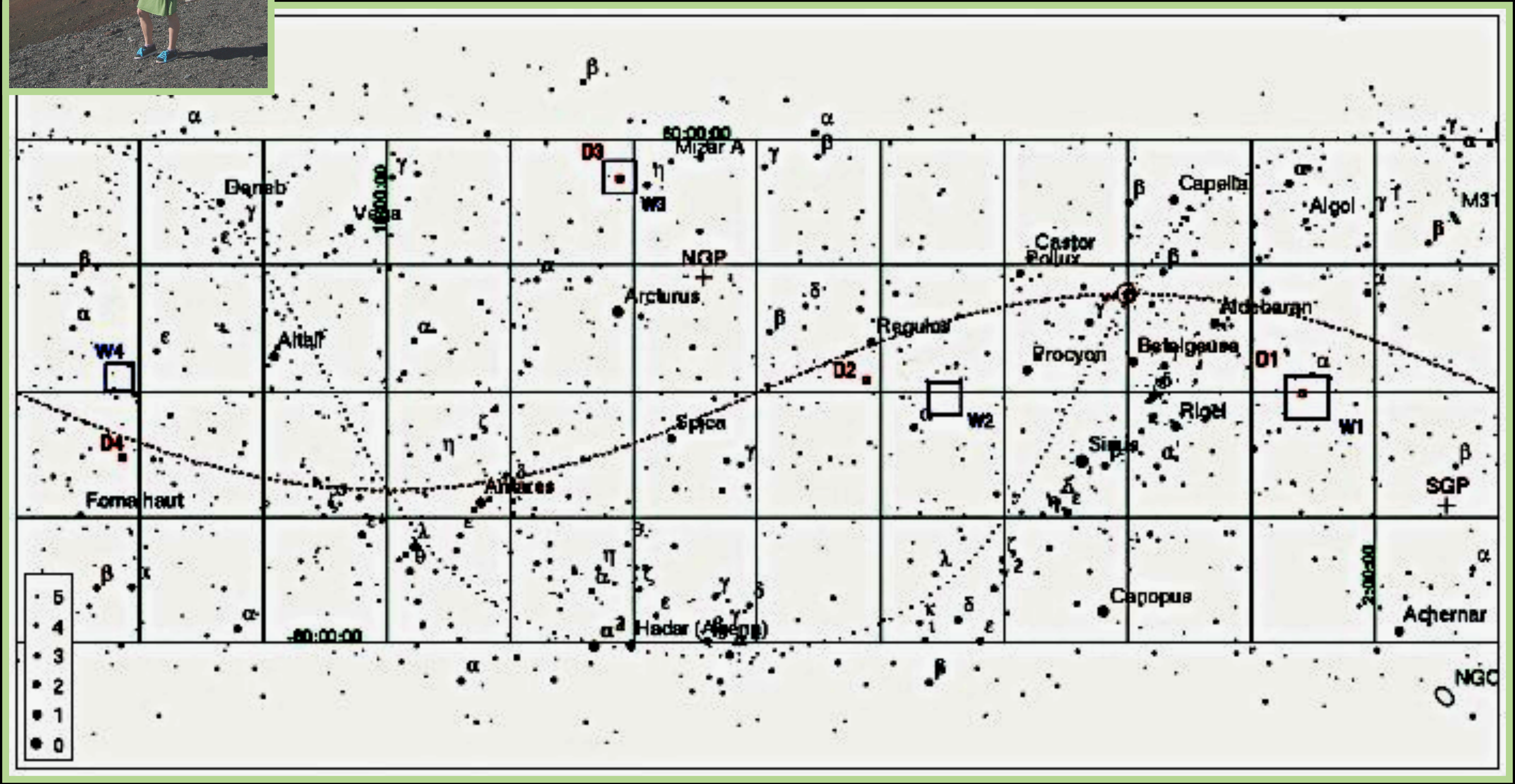
shear *magnification*

Magnification & Shear are *complementary*.
Both should be exploited to maximize what we can learn from our observations.

CFHTLenS Clusters

CFHTLenS



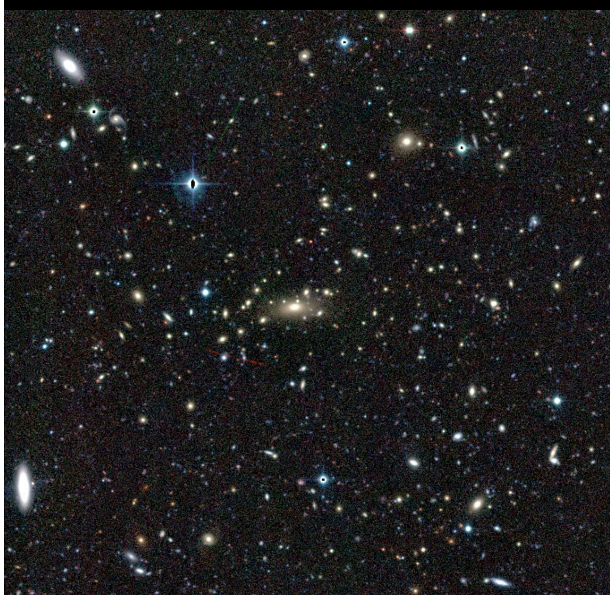


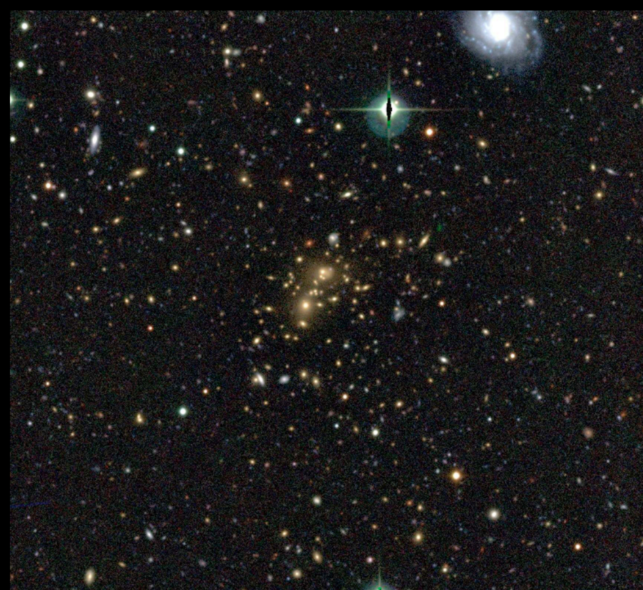
Canada-France-Hawaii Telescope Legacy Survey: 4 Wide fields ~ 154 deg^2

3D-MF Galaxy Clusters

- **3D-Matched-Filter Galaxy Cluster Finder (Milkeraitis et al. 2010)**
- **Searches for regions of sky matching expected luminosity profile & radial profile ⇒ Likelihood maps of sky**
- **3D: discrete redshift bins**
- **Cluster Candidates = Peaks in Likelihood maps**
- **~ 18,000 galaxy clusters 0.2 < *z* < 1**

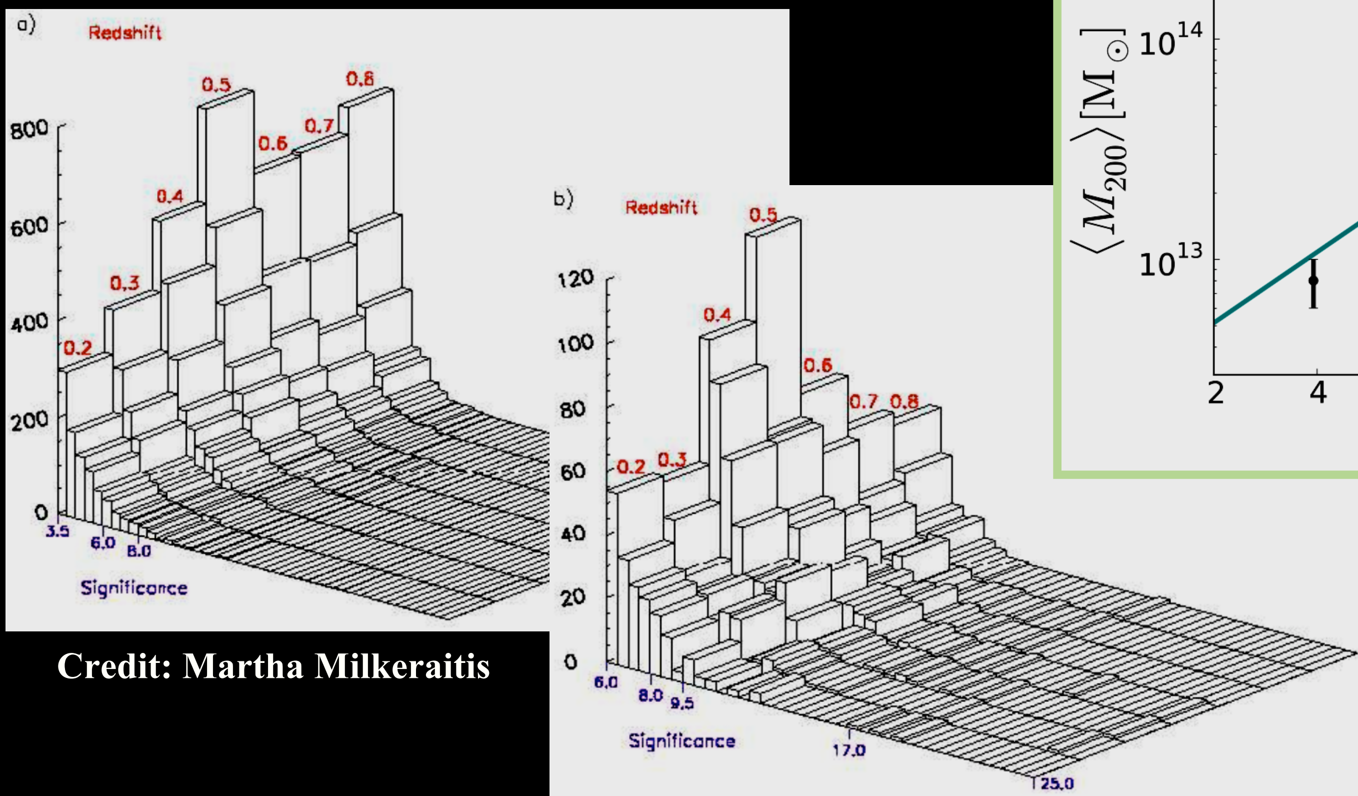
PUBLICLY AVAILABLE CLUSTER CATALOG:
`cfhtlens.org`



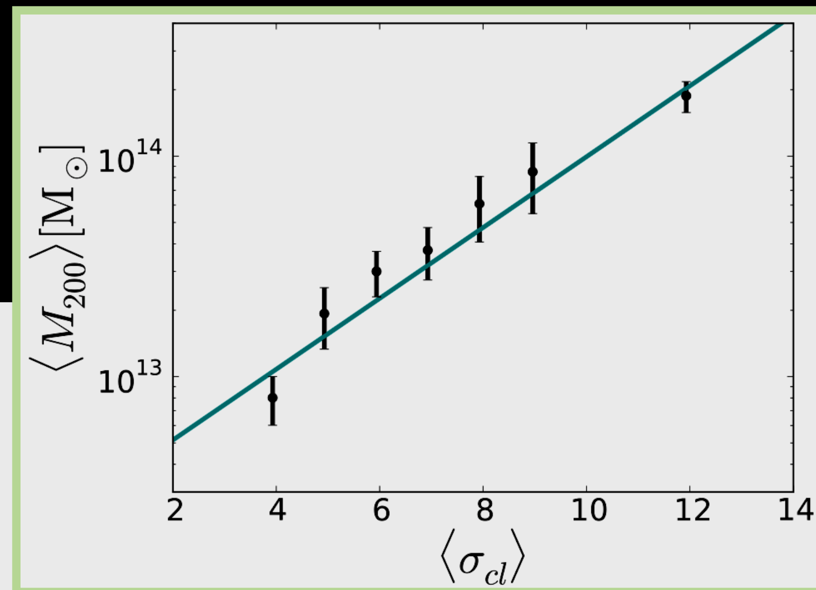


Cluster Lenses

- **Significance of Likelihood Peak σ_{cl}**



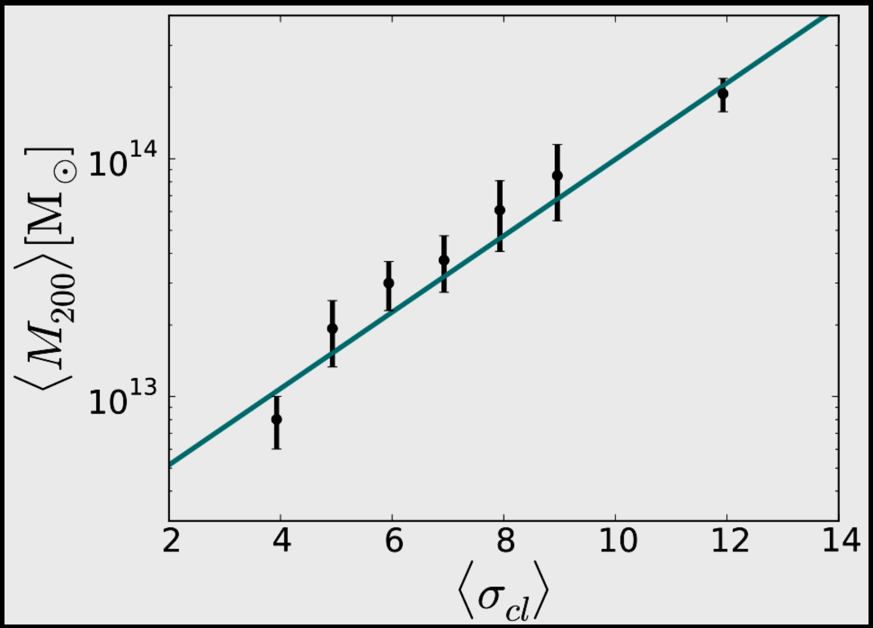
Credit: Martha Milkeraitis



Ford et al. 2014b

- **Completeness:** 100% for $\geq 2.5 \times 10^{14}$ M_{sun}, > 86% for $\geq 5 \times 10^{13}$ M_{sun}
- **False Detection Rate:** < 1% for $\geq 2.5 \times 10^{14}$ M_{sun}, < 15% for $\geq 5 \times 10^{13}$ M_{sun}

Richness N_{200}



Ford et al. 2014b

σ_{cl}

M_{200}^{prelim}

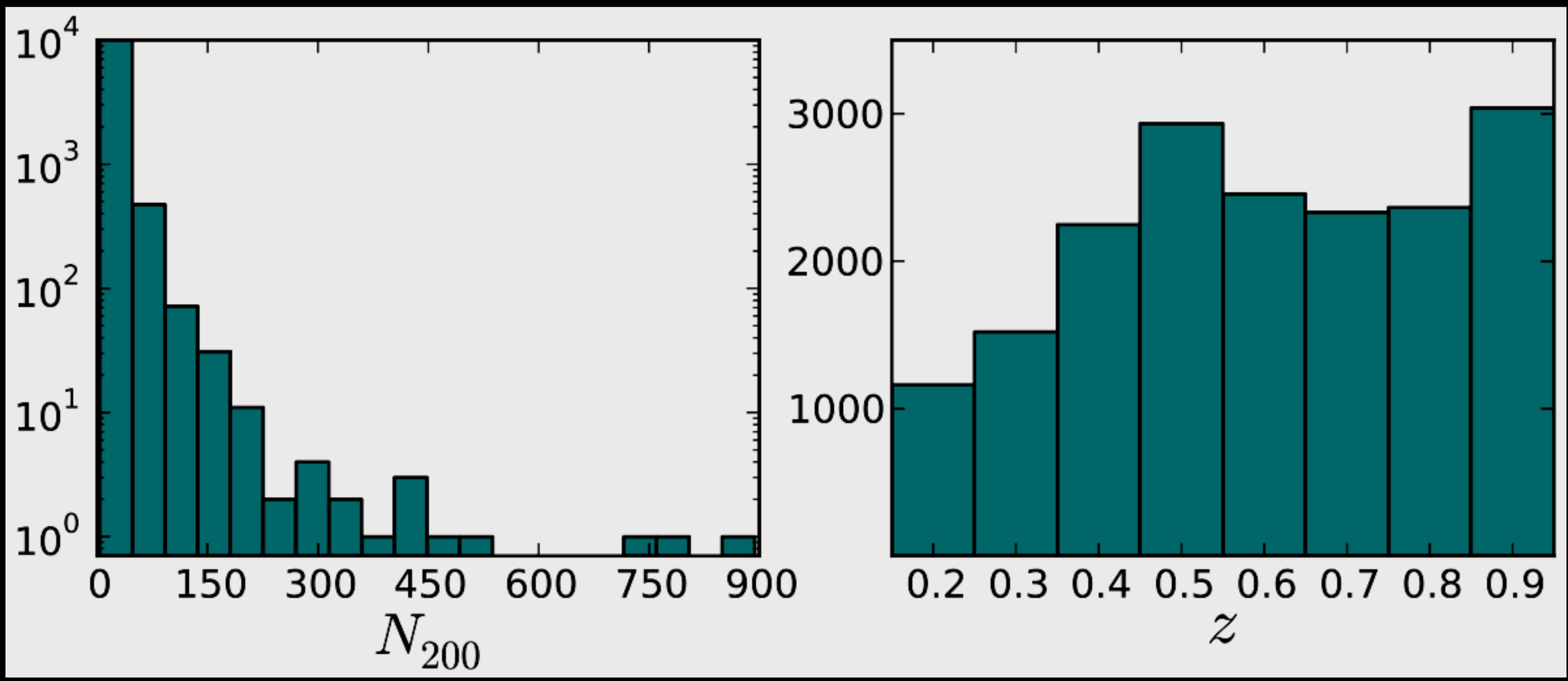
R_{200}

N_{200}

N_{200} includes all galaxies…

- **within R_{200} estimated from shear**
- **brighter than absolute i Magnitude -19.35**
- **within $\Delta z < 0.08\ (1+z)$**
- **background density subtracted**

Cluster Distributions



Ford et al. 2014b

Components of Modeling

Main Halo: NFW profile.

$$\rho_{NFW} = \frac{\delta_c \rho_{crit}(z)}{(r/r_s)(1 + r/r_s)^2}$$

Navarro, Frenk & White (1997)

2-halo term:

Account for neighboring halos.

Cluster Miscentering:

the center chosen by any cluster-finder is probably not the "real" center.

Composite-Halo Fit:

Account for the wide range of cluster M_{200} and *z* instead of fitting a single average mass, redshift.

NFW: 2 fit parameters (M_{200} & c_{200})

+

Mass-Concentration relation

⇓

Just M_{200} parameter for each halo

Components of Modeling

Main Halo: NFW profile.

2-halo term:
Account for neighboring halos.

Cluster Miscentering:
the center chosen by any cluster-finder is probably not the "real" center.

Composite-Halo Fit:
Account for the wide range of cluster M_{200} and z instead of fitting a single average mass, redshift.

- Dark matter is clustered
- Nearby halos contribute few % signal at large radii
- Depends on cosmology and cluster halo bias*

*We use ΛCDM and b(M,z) from Seljak & Warren (2004)

Components of Modeling

Main Halo: **NFW profile.**

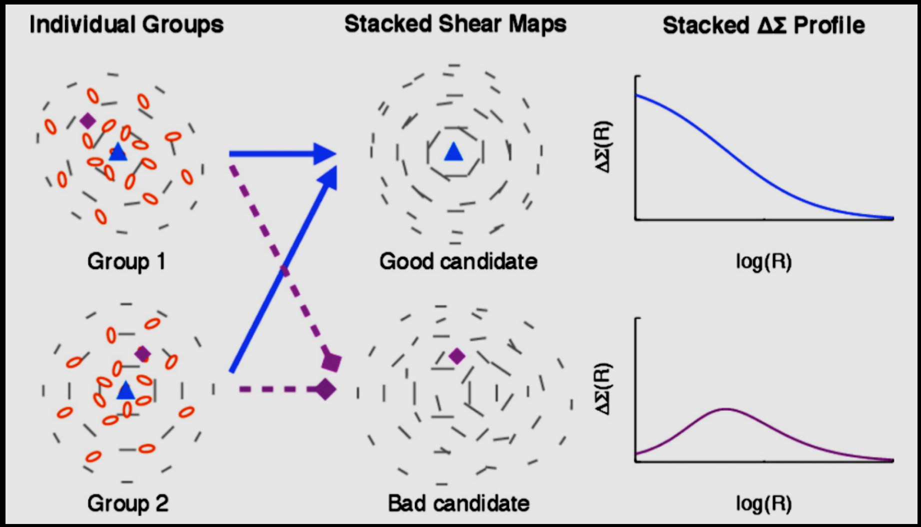
2-halo term:

Account for neighboring halos.

Cluster Miscentering:
the center chosen by any cluster-finder is probably not the “real” center.

Composite-Halo Fit:

Account for the wide range of cluster M_{200} and z instead of fitting a single average mass, redshift.



George et al. 2012

Wrong centers will dilute the signal on small scales.

Components of Modeling

Main Halo: **NFW profile.**

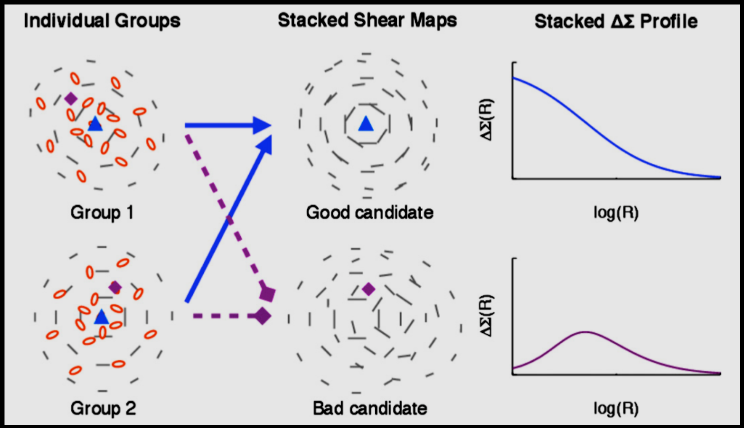
2-halo term:

Account for neighboring halos.

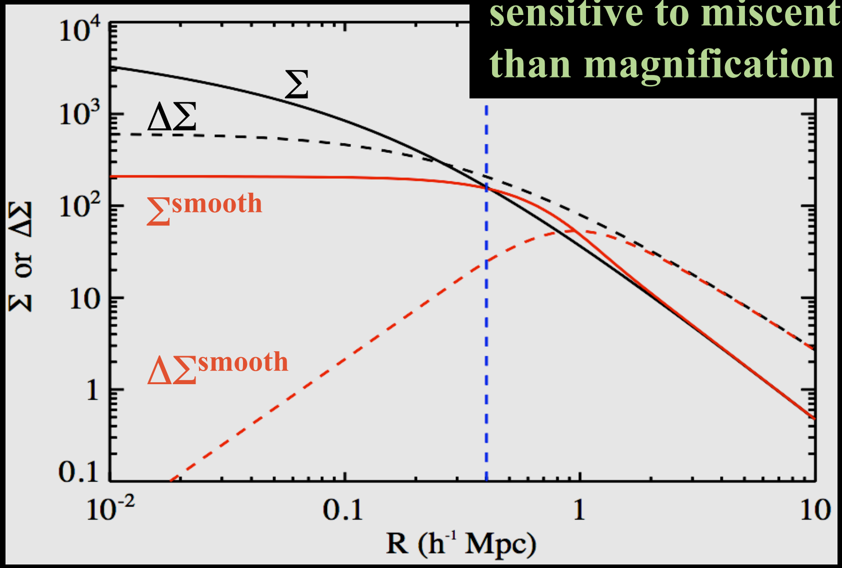
Cluster Miscentering:
the center chosen by any cluster-finder is probably not the "real" center.

Composite-Halo Fit:

Account for the wide range of cluster M_{200} and z instead of fitting a single average mass, redshift.



Shear is much more sensitive to miscentering than magnification



Johnston et al. 2007

Components of Modeling

Main Halo: NFW profile.

2-halo term:

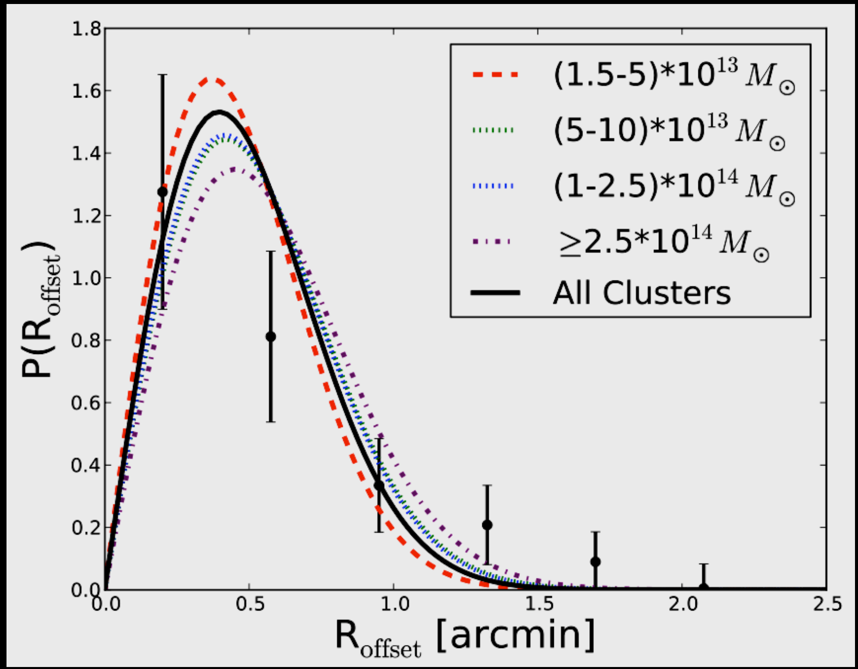
Account for neighboring halos.

Cluster Miscentering:
the center chosen by any cluster-finder is probably not the "real" center.

Composite-Halo Fit:

Account for the wide range of cluster M_{200} and z instead of fitting a single average mass, redshift.

Assume 3D-MF centers have a Gaussian distribution about the "true" centers



Ford et al. 2014a

$$P(R_{off}) = \frac{R_{off}}{\sigma_{off}^2} e^{-\frac{1}{2}\left(\frac{R_{off}}{\sigma_{off}}\right)^2}$$

Data points measured using mock catalogs of Kitzbichler & White (2007)

Components of Modeling

Main Halo: NFW profile.

2-halo term:
Account for neighboring halos.

Cluster Miscentering:
the center chosen by any cluster-finder is probably not the "real" center.

Composite-Halo Fit:
Account for the wide range of cluster M_{200} and z instead of fitting a single average mass, redshift.

Mass-Richness scaling relation:

$$M_{200} = M_0 \left(\frac{N_{200}}{20} \right)^{\beta}$$

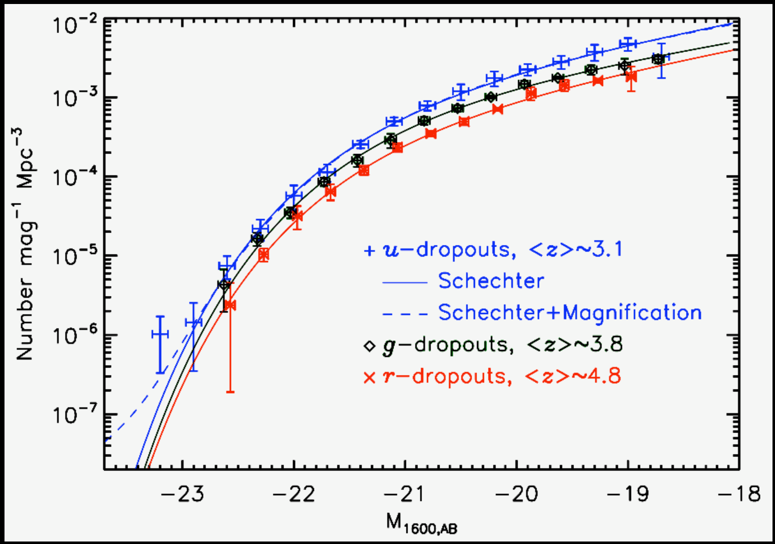
- Each measurement contains many stacked clusters
- Fit a scaling relation (M_0 & β)
- Convert N_{200} distribution to M_{200}
- Account for range of M_{200} & redshift

Cluster Magnification in CFHTLenS

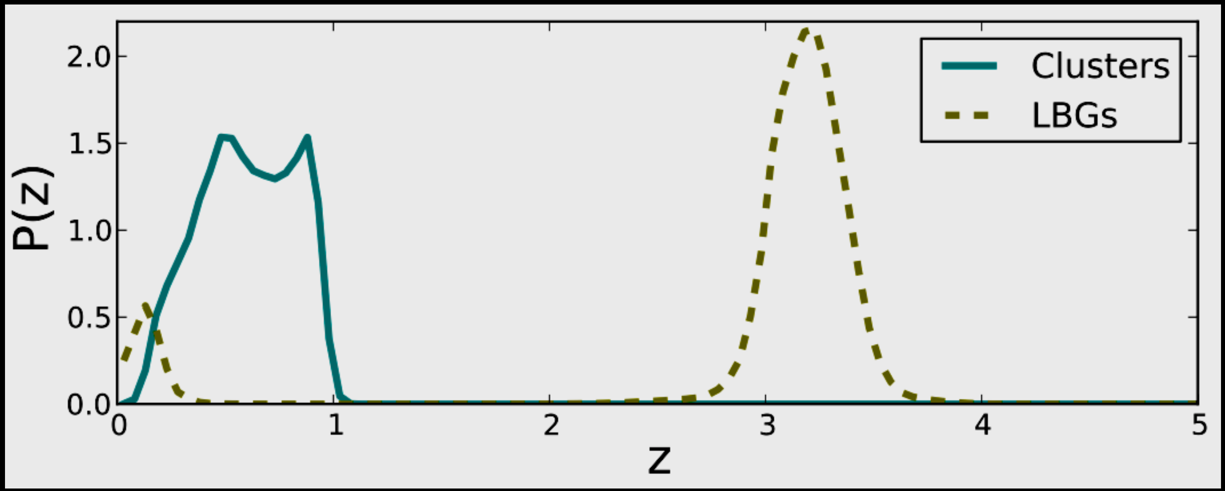
Sources

- Lyman-break galaxies (*u*-dropouts)
- ~ 120,000 LBGs
- we know Luminosity Functions, optimal weight factor (α-1)
- z ~ 3 (except for contamination…)

$$n(m,\theta)dm = \mu^{\alpha-1} n_o(m,\theta)dm$$



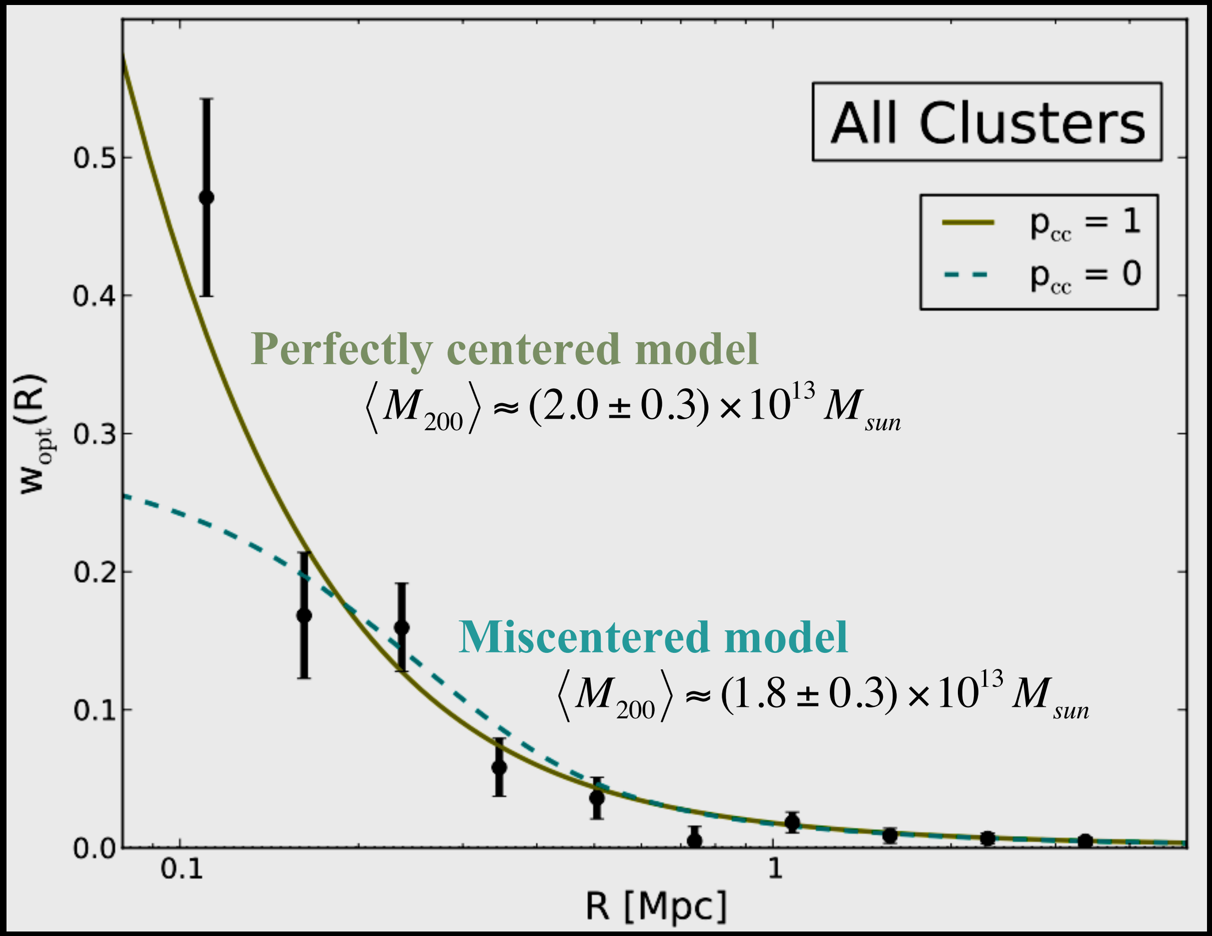
van der Burg et al. 2010



Ford et al. 2014a

All clusters stacked

9.7σ
detection significance



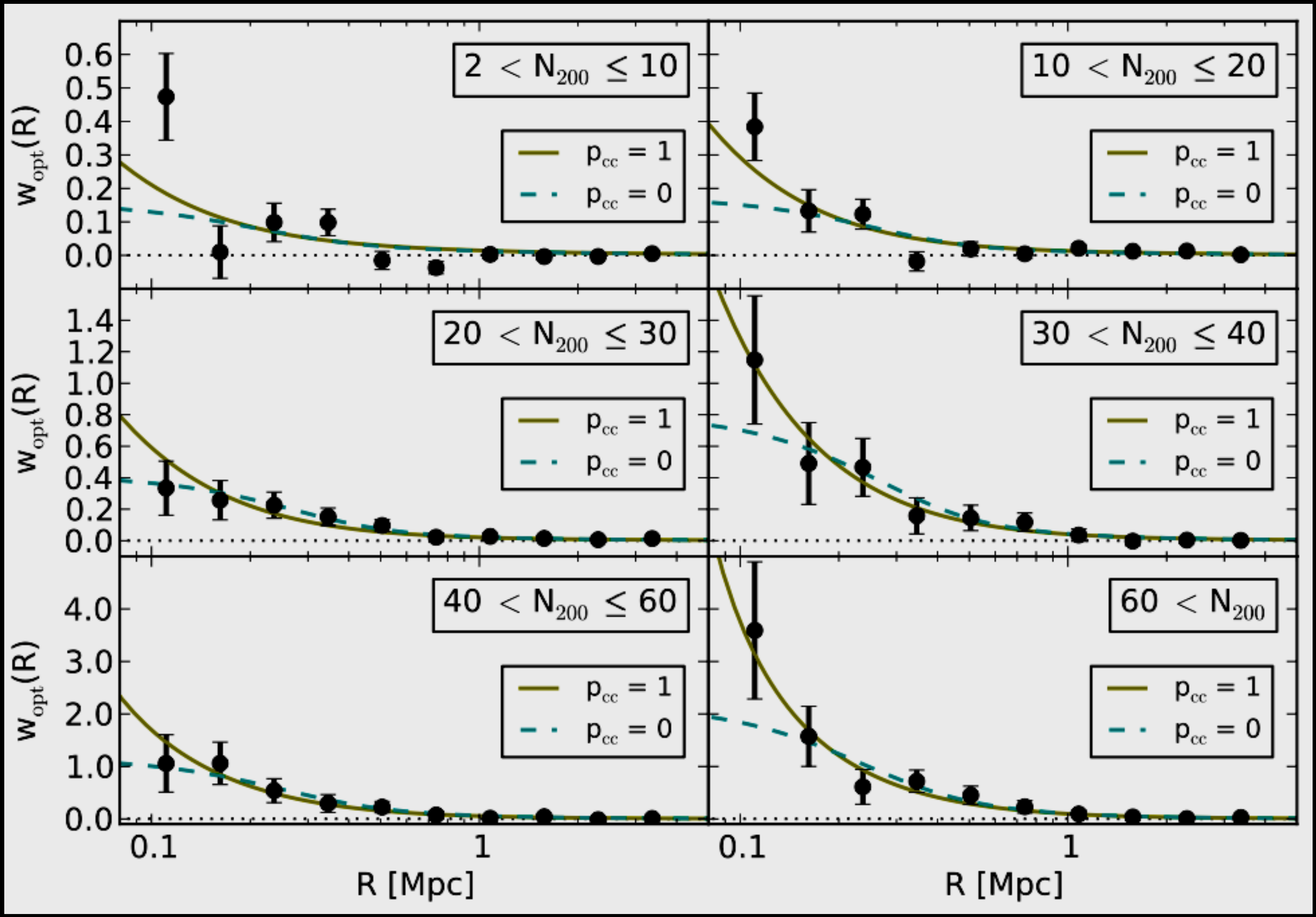
Ford et al. 2014a

Composite - NFW Model:

- ✓ Accounts for range of masses & redshifts
- ✓ Fits a power-law mass-richness scaling relation

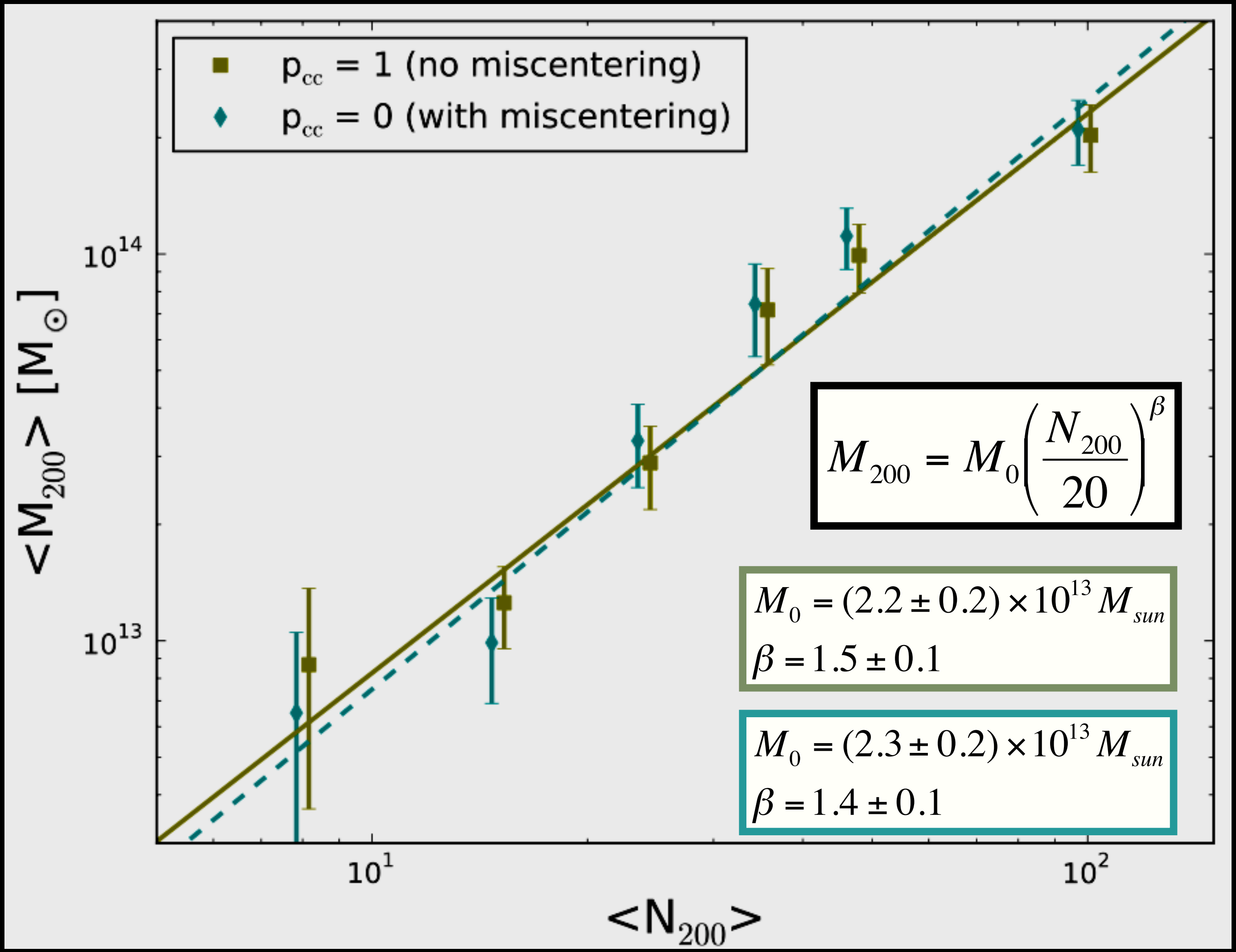
Richness Bins

Strength of magnification signal scales with N_{200}



Ford et al. 2014a

Mass - Richness Scaling



Ford et al. 2014a

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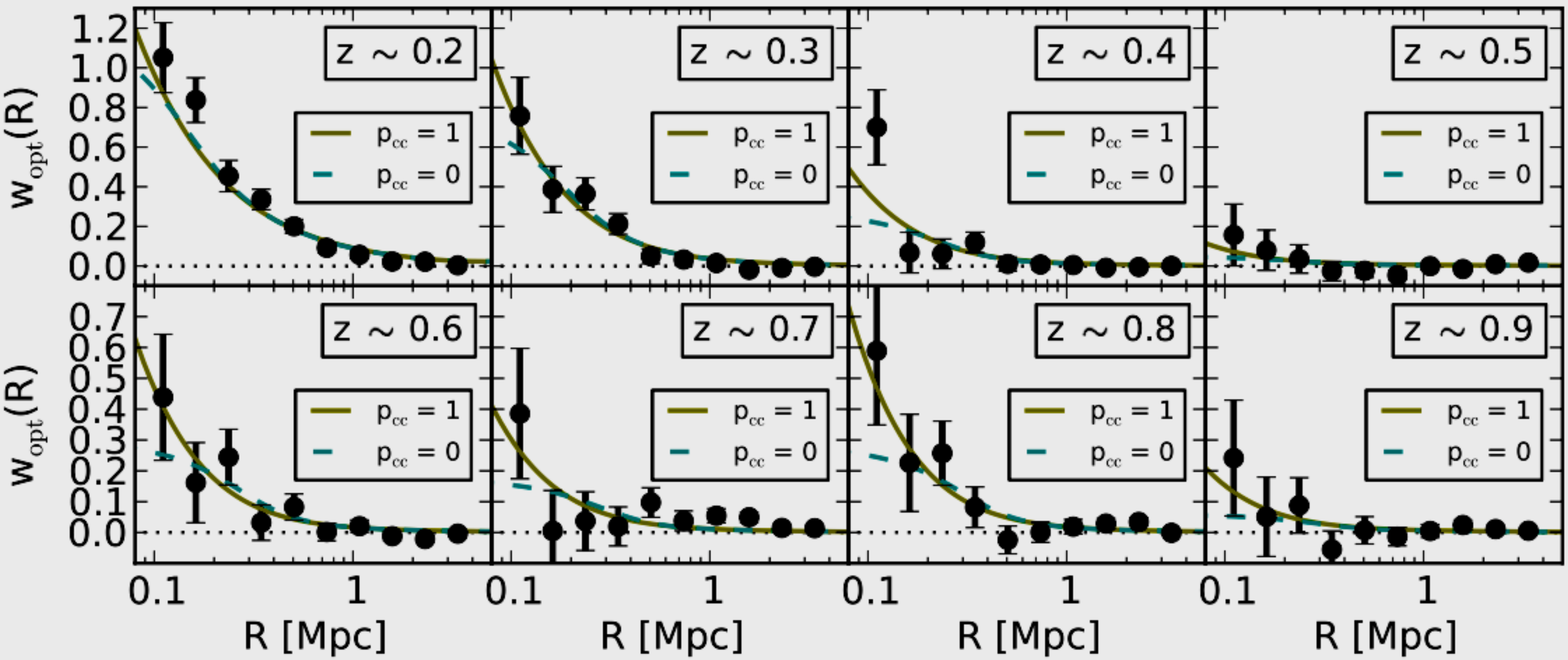
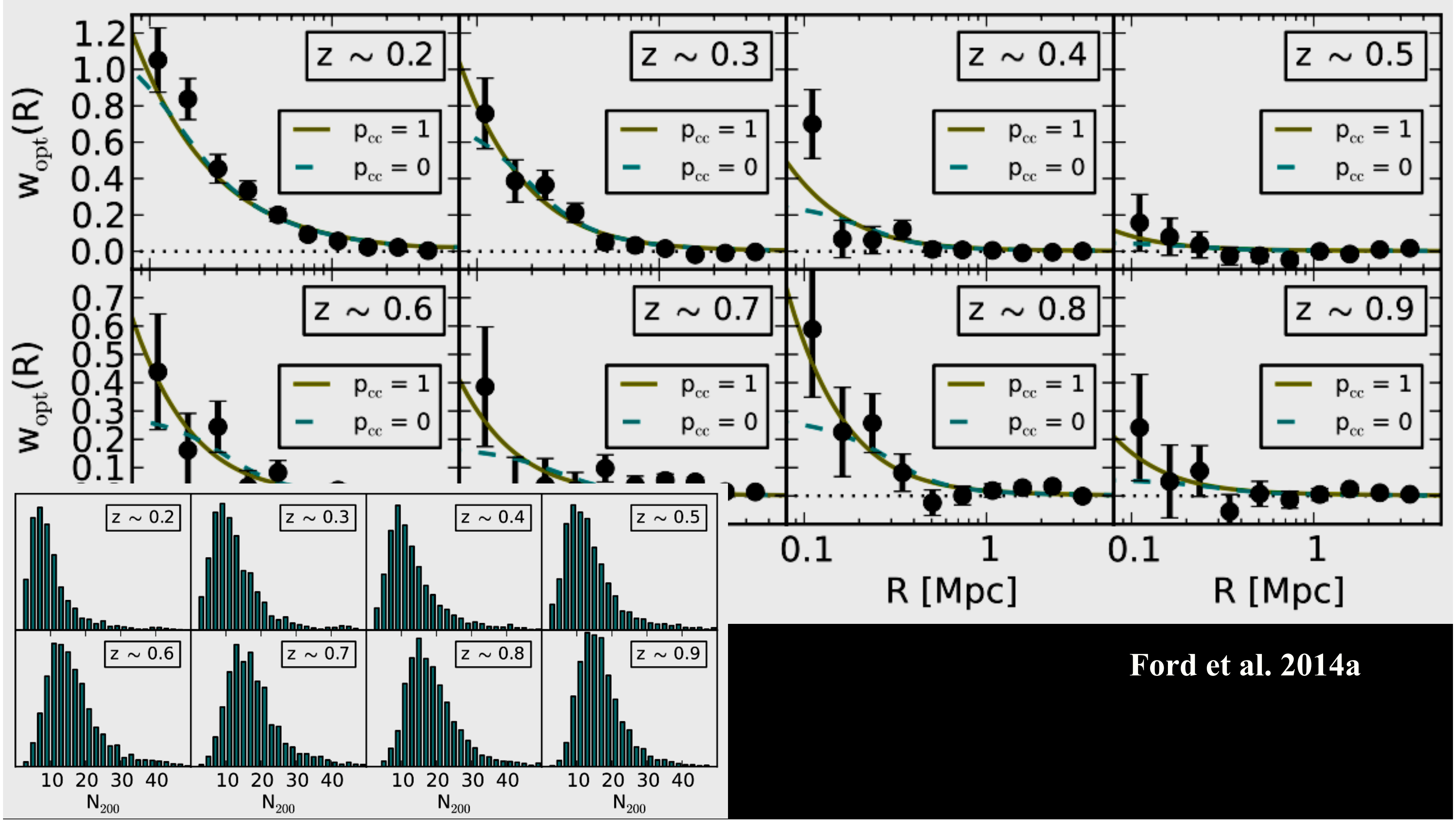
Redshift Bins



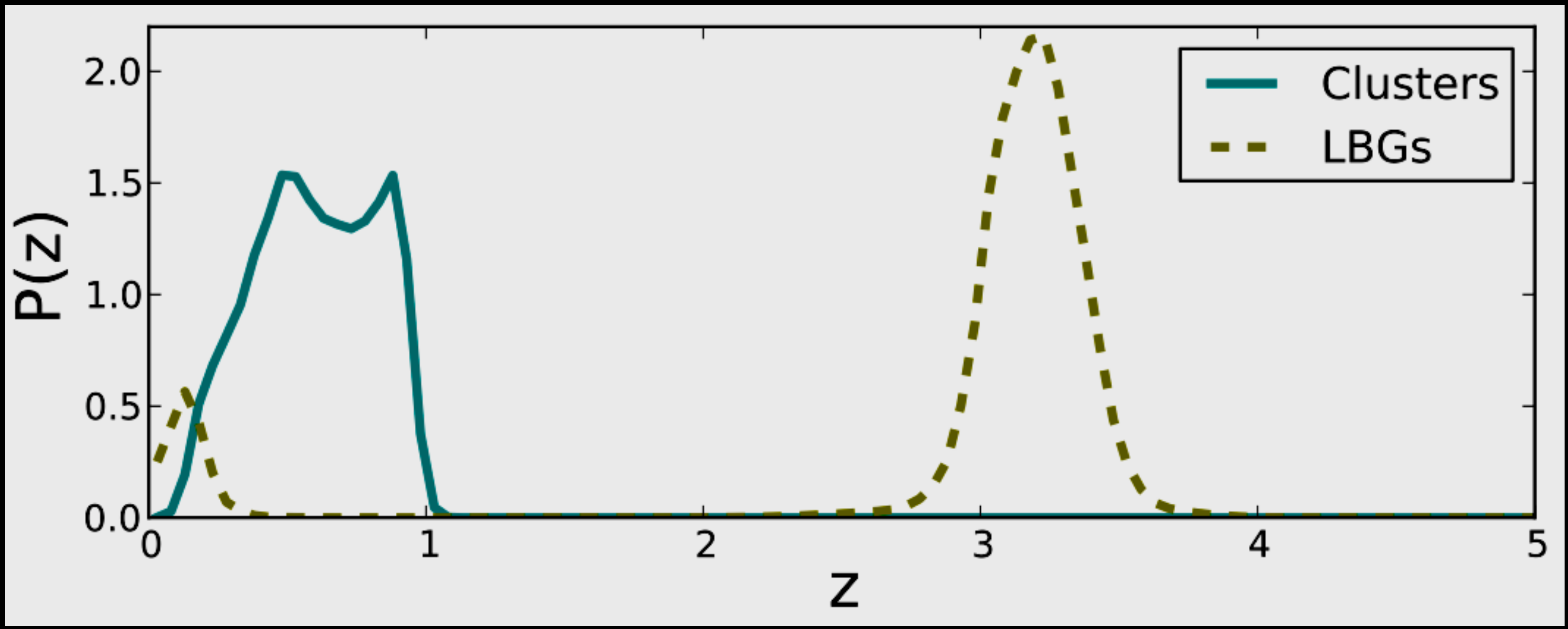
Ford et al. 2014a

Redshift Bins



Ford et al. 2014a

Contamination



Ford et al. 2014a

- Intrinsic physical clustering between clusters and low-z galaxy contaminants?
- Physical cross-correlation signal should be order of magnitude stronger than lensing-induced correlations…

Components of Modeling

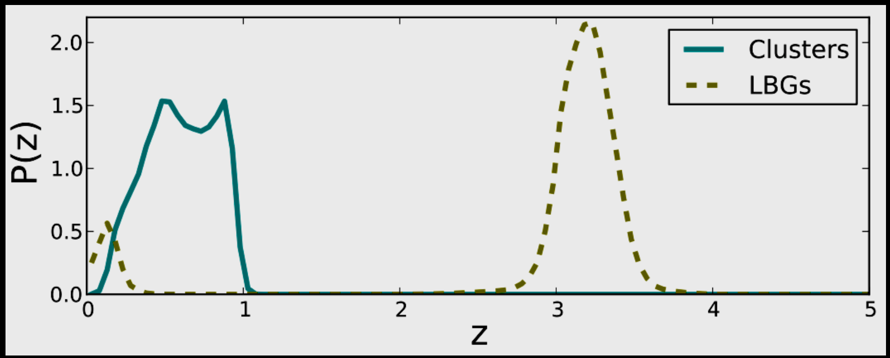
Main Halo: NFW profile.

2-halo term:
Account for neighboring halos.

Cluster Miscentering:
the center chosen by any cluster-finder is probably not the "real" center.

Composite-Halo Fit:
Account for the wide range of cluster M_{200} and z instead of fitting a single average mass, redshift.

Source Contamination:
low-z contamination leads to non-lensing correlations due to lens-source physical clustering.



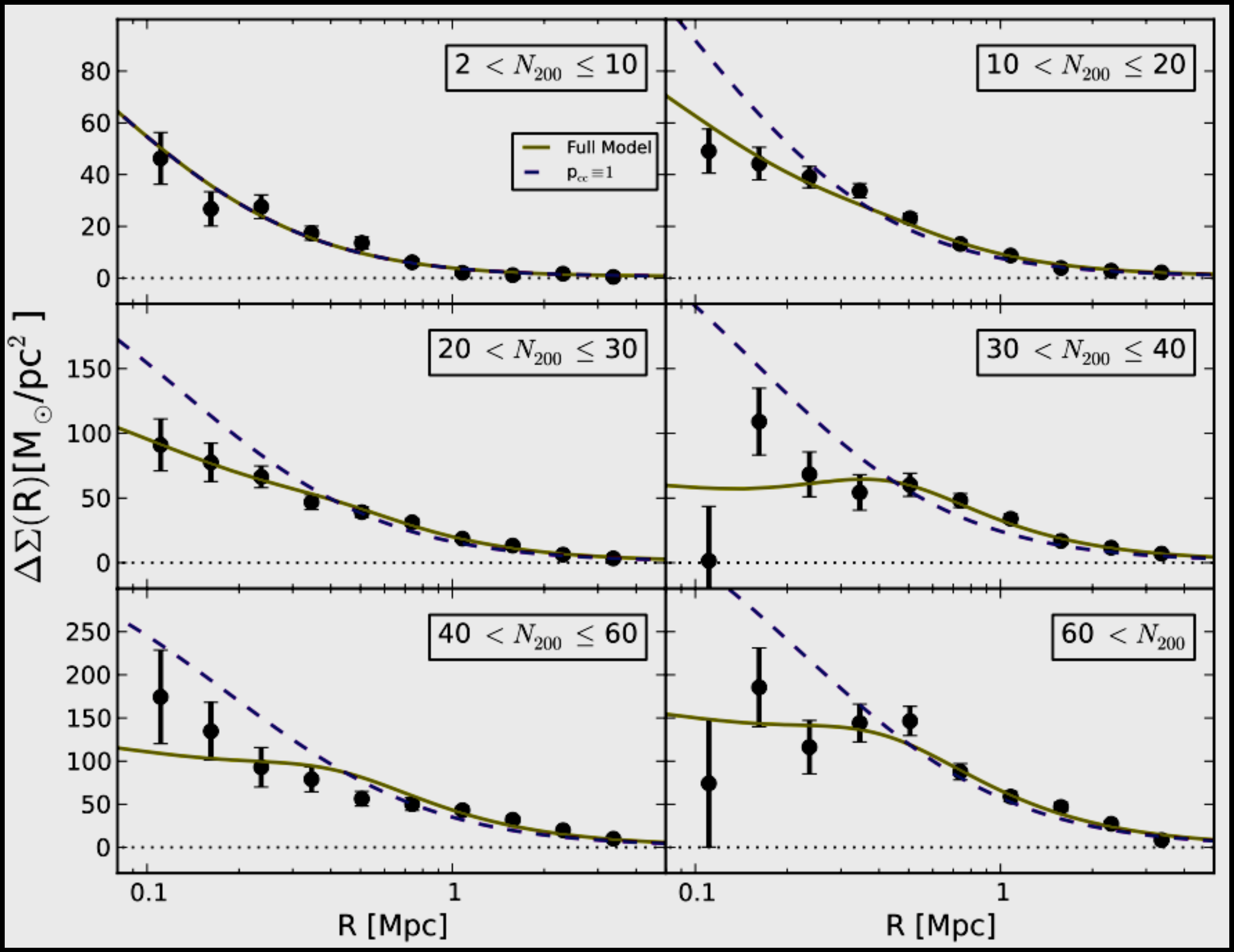
Ford et al. 2014a

Include intrinsic clustering term where populations overlap:

$$w_{opt}(R,z) = f_{lens}(z) \cdot w_{lens}(R,z) + f_{clustering}(z) \cdot w_{clustering}(R,z)$$

Cluster Weak Lensing in CFHTLenS

N_{200}-binned Shear

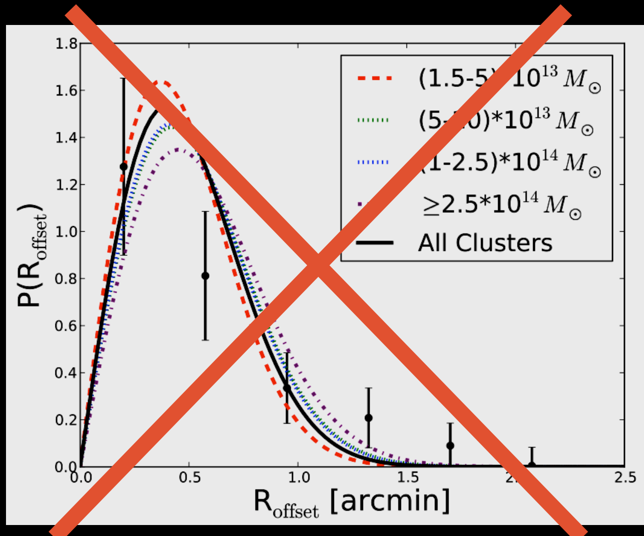


Perfectly centered model

Full model including miscentering

Ford et al. 2014b

Miscentering

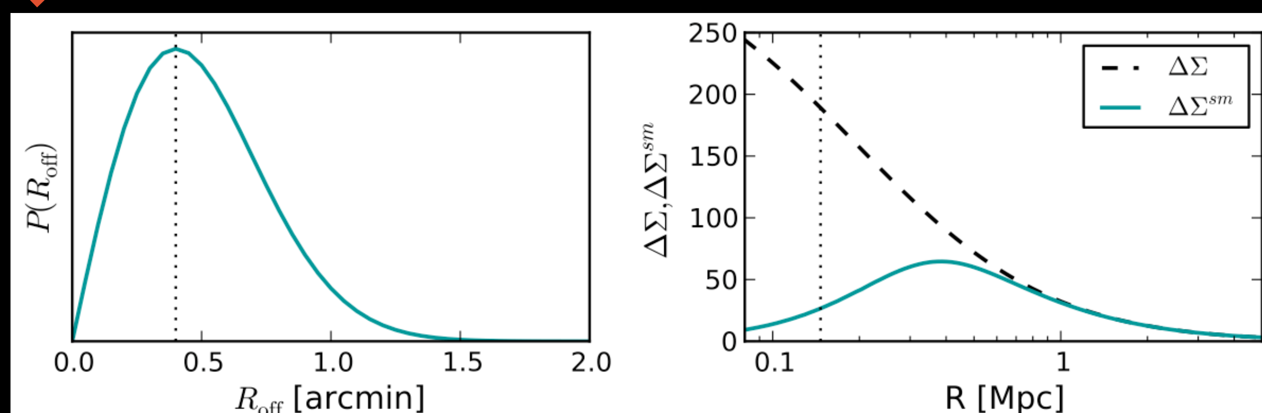


Ford et al. 2014a

Shear is much more sensitive to miscentering
⇒ now we FIT for the offsets

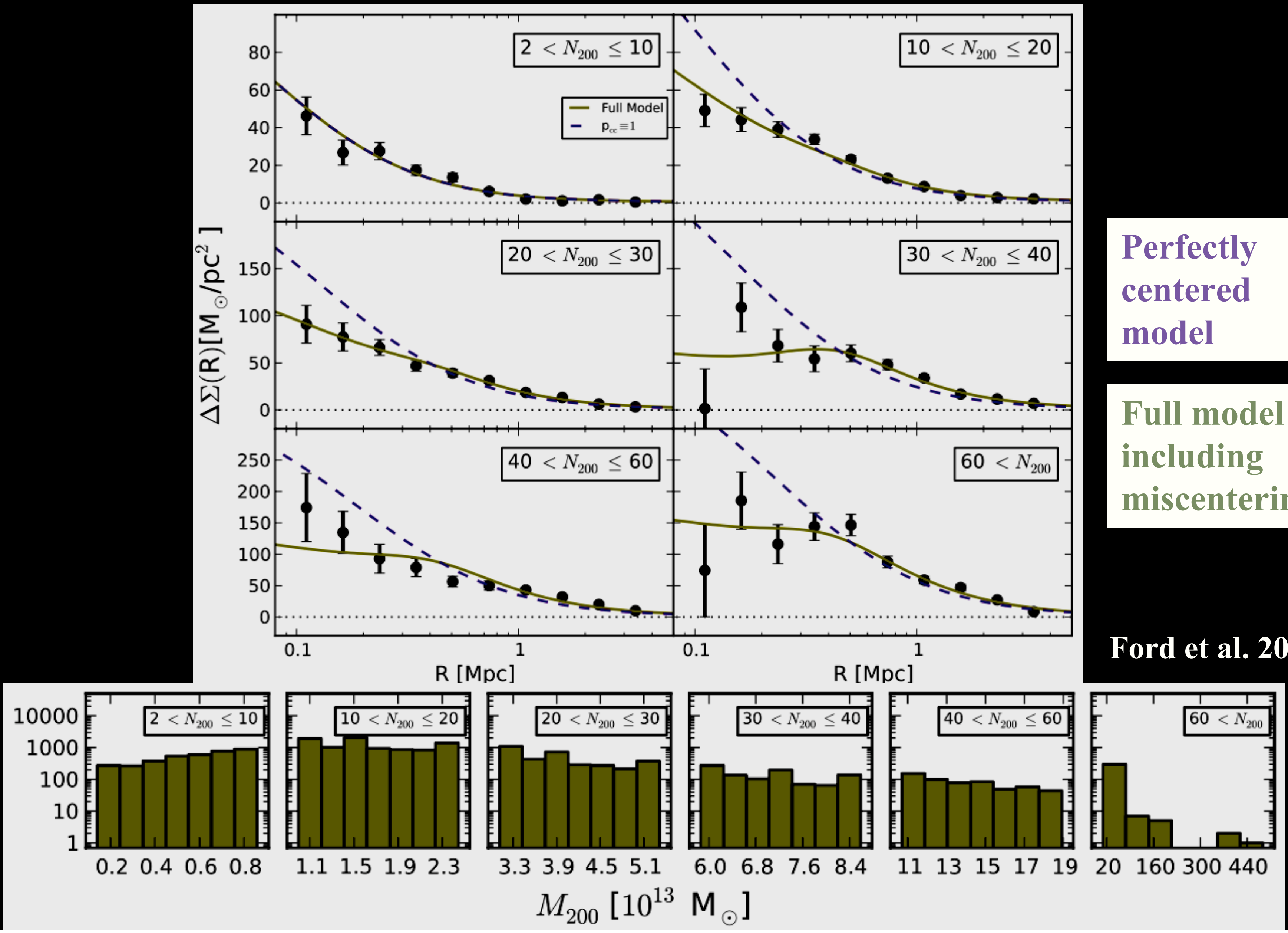
- σ_{off} **= width of the Gaussian offset distribution**
- p_{cc} **= fraction of clusters that have been correctly centered**

$$P(R_{off}) = \frac{R_{off}}{\sigma_{off}^2} e^{-\frac{1}{2}\left(\frac{R_{off}}{\sigma_{off}}\right)^2}$$



Ford et al. 2014b

N_{200}-binned Shear

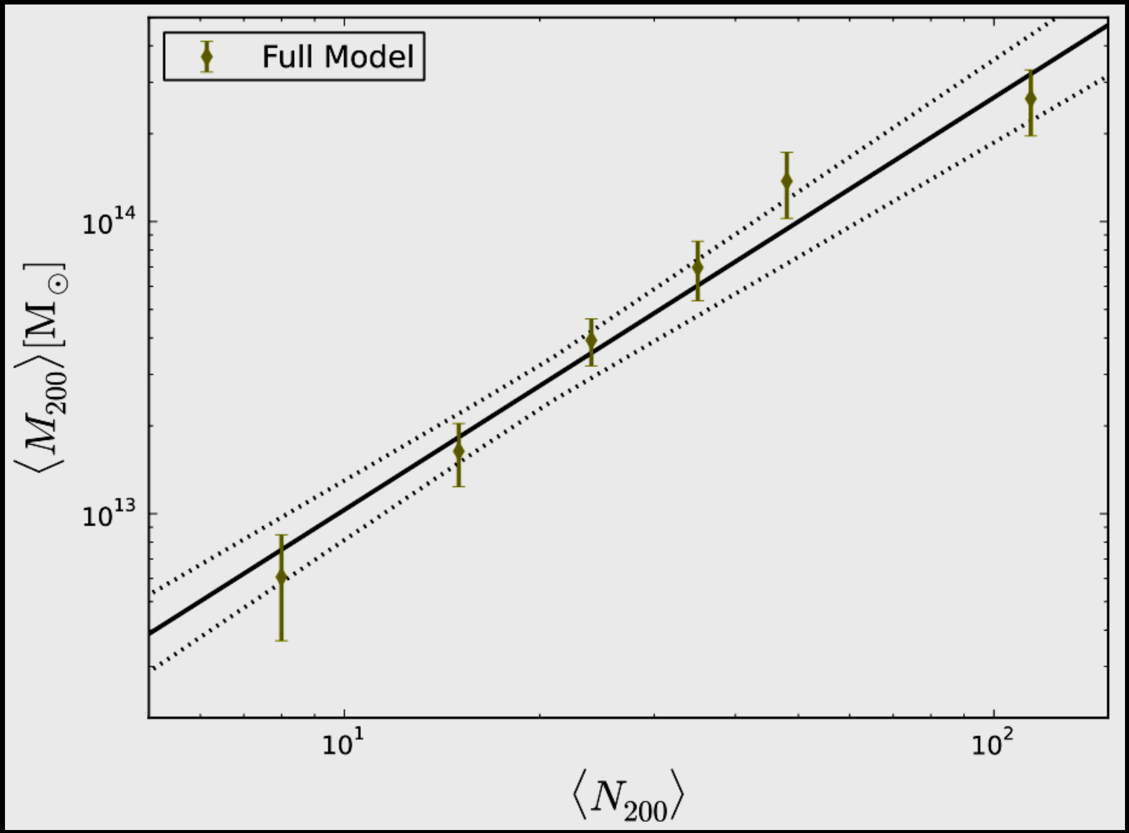


Perfectly centered model

Full model including miscentering

Ford et al. 2014b

Mass-Richness Scaling



Ford et al. 2014b

$$M_{200} = M_0 \left(\frac{N_{200}}{20} \right)^{\beta}$$

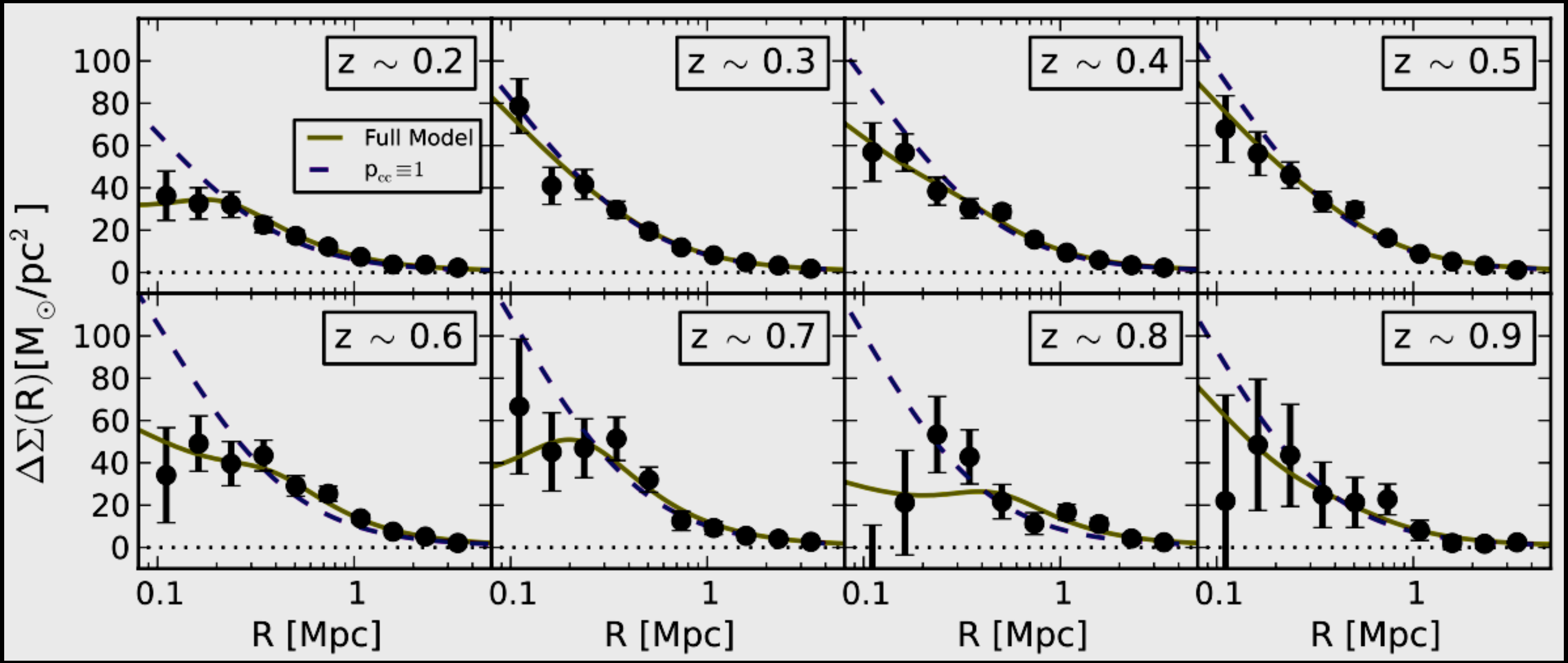
Shear:

$$M_0 = (3.1 \pm 0.5) \times 10^{13} M_{sun}$$
$$\beta = 1.5 \pm 0.2$$

vs. Magnification:

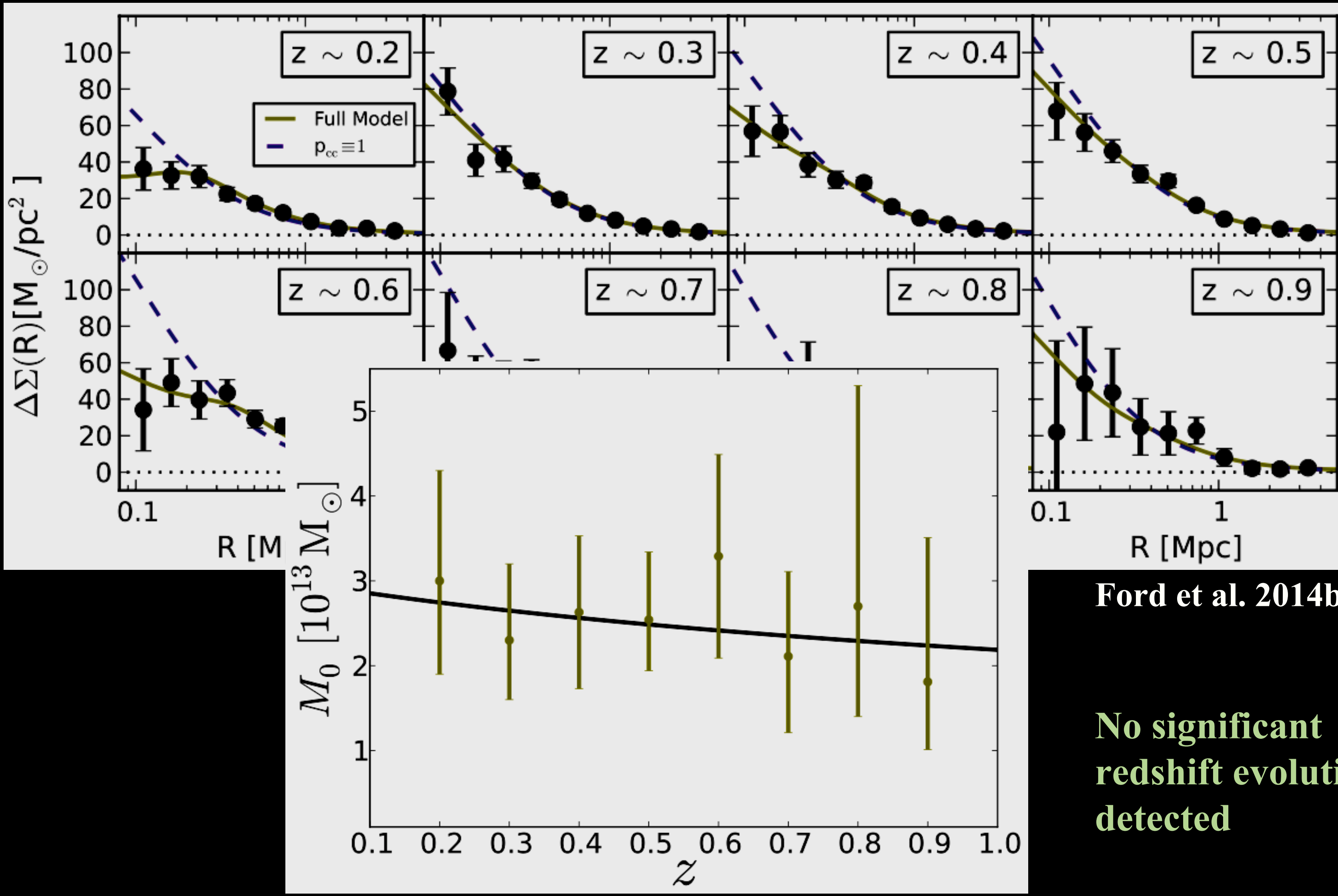
$$M_0 = (2.2 \pm 0.2) \times 10^{13} M_{sun}$$
$$\beta = 1.5 \pm 0.1$$

Redshift Evolution?



Ford et al. 2014b

Redshift Evolution?



Ford et al. 2014b

No significant redshift evolution detected

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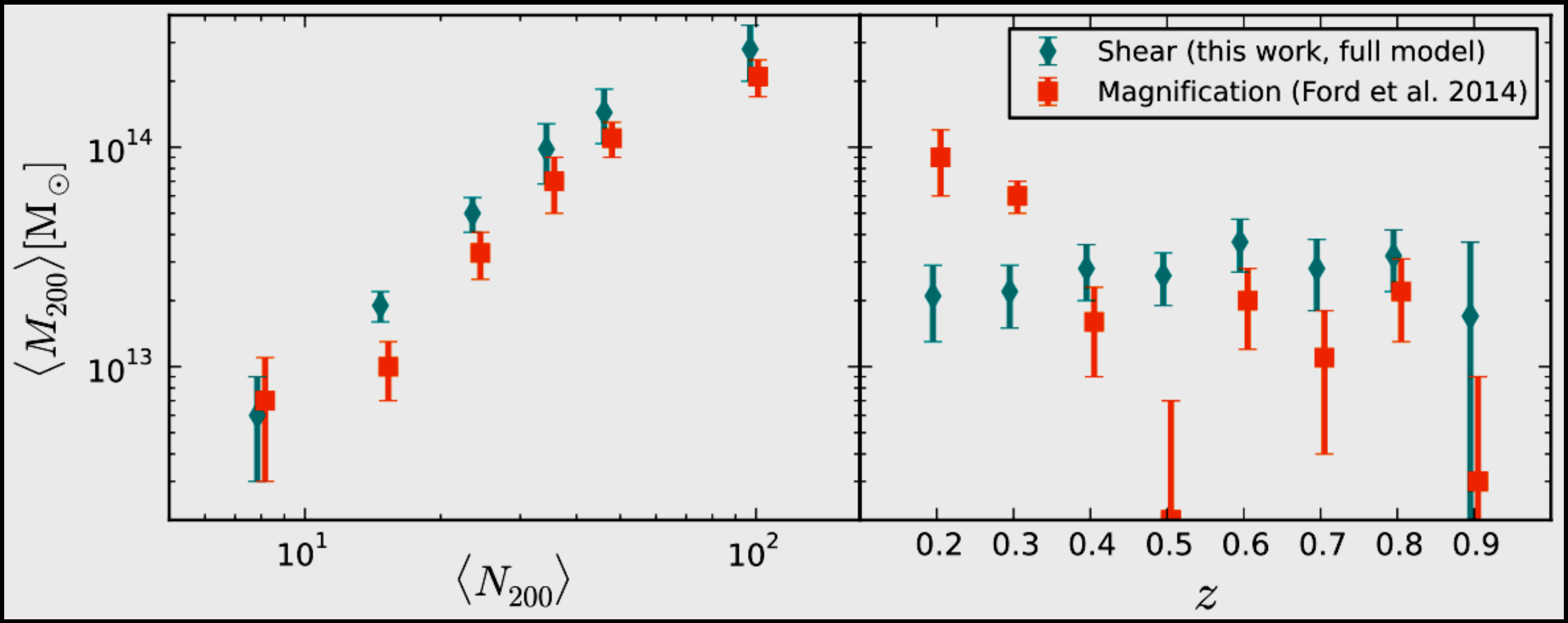
Shear vs. Magnification

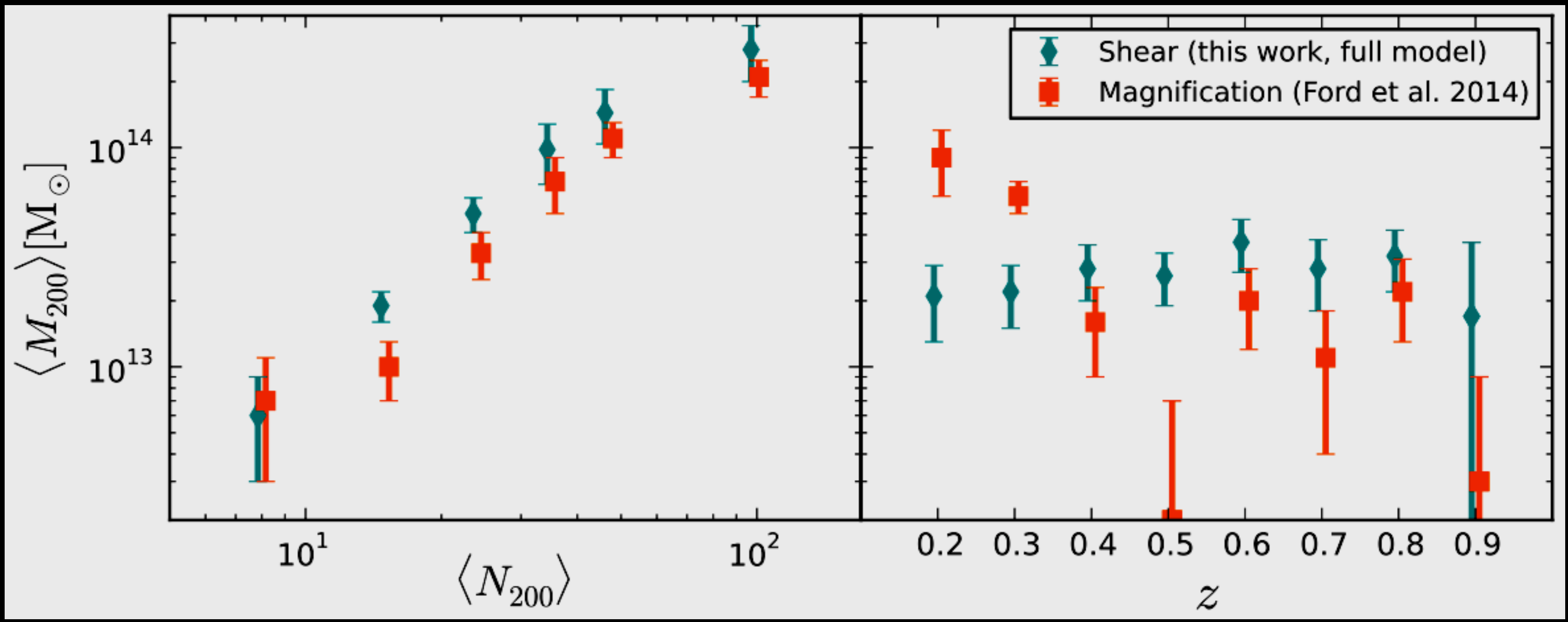


Ford et al. 2014b

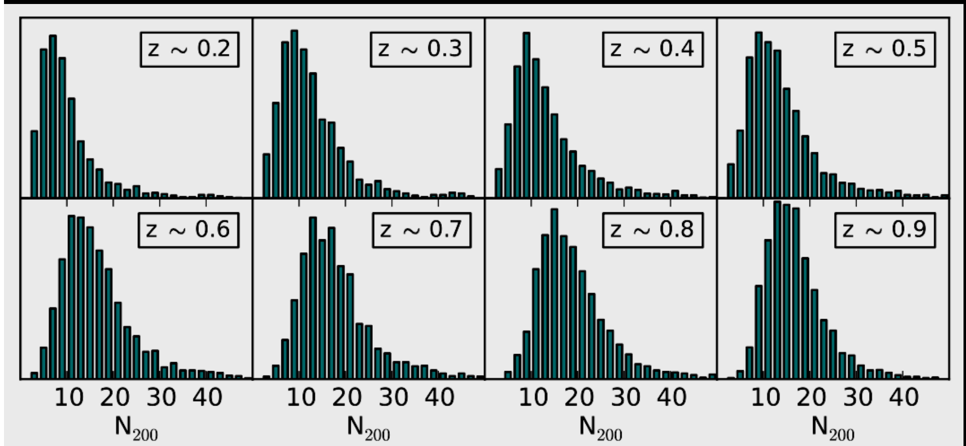
Richness Binned: **Magnification masses consistent with shear but biased low.**
Mass-Richness Scaling: **Slope is consistent, normalization 2σ off**

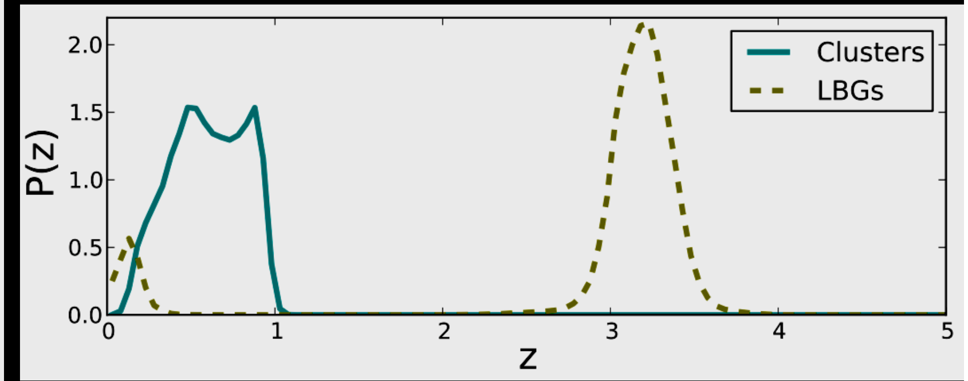
Redshift Binned: **Shear masses are steady, magnification masses fluctuate…**

Shear vs. Magnification



Ford et al. 2014b





Ford et al. 2014a

Future Work

- **Shear-magnification discrepancies:** **magnification comes from free in any shear survey… how to optimally use observational data?**

- **3D-MF Cluster follow-up:** **miscentering analysis, comparing alternative centers, L_X-M scaling, SZ-lensing cross-correlations, detecting filaments, and more…**

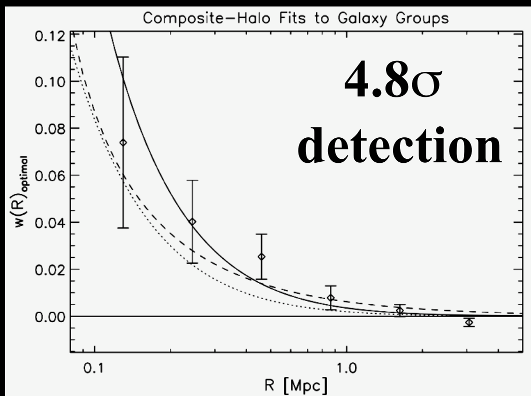
- **Open Source Project:** **cleaning up code for magnification analysis and miscentering modeling (github repository coming soon)**

- **Can we detect dust?** **Dust extinction is λ-dependant, so in principle separable from the magnification signal (e.g. Hildebrandt et al. 2013)**

Summary

COSMOS Magnification

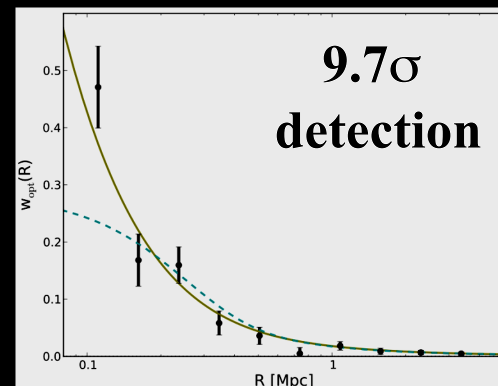
Ford et al. 2012 - arXiv: 1111.3698



1st magnification detection and shear comparison for galaxy clusters

CFHTLenS Magnification

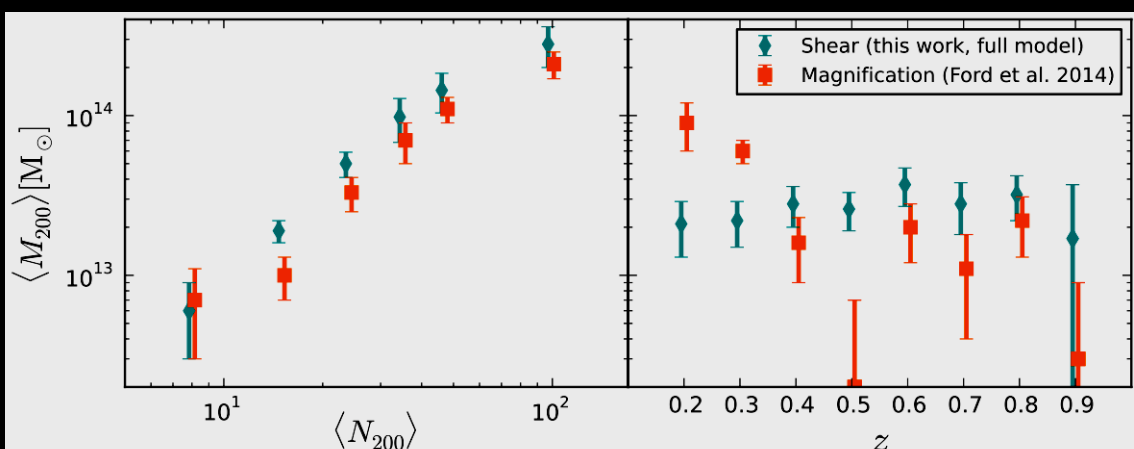
Ford et al. 2014a - arXiv: 1310.2295



Full redshift and richness binned analysis of cluster magnification and shear

CFHTLenS: Shear vs. Magnification

Ford et al. 2014b - arXiv: 1409.3571



PUBLICLY AVAILABLE CLUSTER CATALOG:
`cfhtlens.org`

Thanks for Listening!